Economic Behaviour and Groundwater Contamination in Bangladesh and Mexico

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Declaration for PhD thesis

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Abstract

In this research the economic behaviour associated with the consumption of arsenic and fluoride contaminated groundwater and the use of arsenic and fluoride removal technologies in affected areas of Bangladesh and Mexico is analysed using a number of tools of economic analysis including analysis of household surveys and stated preference methods. In the first section, a health production function approach is used in order to estimate the economic costs of arsenicosis in rural households of Shahrasti, Bangladesh. Then, experimental data from rural communities in Bangladesh are used to assess the adoption of groundwater arsenic removal technologies in relation to risk and time preferences. The identification of such preferences is important because they determine people's propensity to use arsenic removal technologies and their ability to avoid arsenic related illnesses. Further, time inconsistent preferences can trigger self-control related problems like procrastination in the use of water filters. In the second section, a contingent valuation survey is used to elicit household willingness to pay responses for safe drinking water in Zacatecas, Mexico. The objective is to investigate households' willingness to pay for improved water quality through the installation of a new filtration system to remove fluoride and arsenic from groundwater. It was found that individuals' subjective perceptions of contamination might change their attitude towards the installation of water purification systems, thereby changing the effective price of potable groundwater that they are willing to pay. Different types of contamination (by arsenic and fluoride in this case) had differing effects on values. Value estimates also changed as the socioeconomic profiles of survey respondents changed. Further interdisciplinary research was conducted in order to achieve a better understanding of the problem of environmental contamination with arsenic, fluoride and heavy metals in Mexico.

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Preface

Arsenic contamination of groundwater aquifers affects several countries worldwide posing a serious threat to the health of millions of people. Bangladesh in South Asia and Mexico in Latin America are among the most affected countries by this serious environmental problem. An analysis about the similarities and differences, success and failure of the policies (or lack of them) designed for coping with the problem will allow new insights for the understanding and solution of the phenomenon. This work is divided into two sections. Section A deals with groundwater contamination in Bangladesh. Section B presents my research on groundwater contamination in Mexico.

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A. Groundwater Contamination in Bangladesh

Chapter 1

Groundwater Contamination in Bangladesh: An Introduction

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1. Introduction

Arsenic contamination of groundwater aquifers affects several countries worldwide posing a serious threat to the health of millions of people. Bangladesh is the most affected country by this serious health problem. Different studies have estimated that between 30 and 85 million people drink water from arsenic –contaminated tube wells in Bangladesh (Smith, Lingas and Rahman 2000, BGS/DPHE 2001, Michael and Voss 2008). The presence of inorganic arsenic at toxic levels in the aquifers represents a serious risk mainly for people living in rural areas who rely on arsenic contaminated groundwater as their only source of drinking water (Heikens 2006 and Alvarez and Uribe 2006). The aim of the first section of this research is to analyse the economic behaviour associated with the consumption of arsenic contaminated groundwater and the use of arsenic removal technologies in severely affected areas of Bangladesh. In the following sections of this introductory chapter a brief description of the effects of arsenic on human health and food security will be discussed. Then, the research question and hypothesis of my research will be presented.

1.1 Arsenic and its effects on human health

Arsenic (***As***) is a metalloid member of group VA of the periodic table. It has the common oxidation states of –3, +3 and +5. The redox states of ***As*** are arsenite ***As***^{III} (H_3AsO_3) and arsenate ***As***^{V} (H_3AsO_4). In nature ***As*** occurs in organic and inorganic compounds. ***As*** and its compounds are present in trace quantities in all rock, soil, water and air. However, concentrations may be higher in certain areas as a result of weathering and anthropogenic activities (WHO 2001, Yu 2005 and Caussy and Priest 2008). Two types of ***As*** poisoning can be distinguished: acute and chronic (also called arsenicosis). Das, Mallick and Sengupta (2003), report that an ingested dose of 70–180 mg of $\boldsymbol{As}^{III}$ leads to fatal acute poisoning, yet a dose of 20 *mg* is life threatening. The symptoms of acute intoxication usually occur 30 minutes after ingestion but may be delayed if it is taken with food. After absorption, $\boldsymbol{As}^{III}$ is transported by blood to other organs. On the first stage of poisoning, the patient may have a metallic taste, associated with a dry mouth and difficulty to swallow. Severe nausea and vomiting, colicky, abdominal pain and profuse diarrhoea suddenly follow. Drowsiness and confusion are often seen along with the development of psychosis associated with paranoid delusions, hallucinations, and delirium. Finally, seizures, coma and death usually due to shock, may occur. In humans who died of acute ***As*** poisoning, the highest ***As*** levels were found in the liver, kidney, intestinal mucosa and spleen (Yu 2005). Following the gastrointestinal phase, multisystem organ damage may occur. If death does not occur in the first twenty-four hours from irreversible circulatory insufficiency, it may result from hepatic or renal failure over the next days. On the other hand, drinking water with high levels of ***As*** over a long period of time (usually from 5 to 20 years) provokes chronic arsenic poisoning or arsenicosis. Absorption of arsenic through the skin is minimal and thus hand–washing, bathing, laundry, etc. with water containing ***As*** do not pose human health risks. Arsenicosis most prominent manifestations involve the skin, blood and neurologic systems and are different to acute poisoning (see table 1). Cutaneous changes due to arsenicosis include melanosis (patchy pigmentation of the skin), hyperkeratosis (thickening of the skin), desquamation and in severe cases gangrene. Anaemia and leucopoenia are highly related with chronic ***As*** exposure (Das, Mallick and Sengupta 2003 and WHO 2001).

Table 1 Clinicopathological findings in acute and chronic arsenic poisoning

	Acute	Chronic
Dermatologic	Capillary flush, contact dermatitis, folliculitis. Hair: delayed loss. Nail: Aldrich – Mees'lines (4–6 weeks post ingestion).	Melanosis, Bowen's disease, facial edema, palmoplantar hyperkeratosis, cutaneous malignancies, hyper pigmentation, desquamation, Raynaud's gangrene (Blackfoot disease).
Neurologic	Hyperpyrexia, convulsions, tremor, coma, disorientation.	Encephalopathy, headache, peripheral polyneuropathy, axonal degeneration.
Gastrointestinal	Abdominal pain dysphagia, vomiting, bloody diarrhoea, garlicky odour to breath and stools, mucosal erosions fatty liver.	Nausea, vomiting, diarrhoea, anorexia, weight loss, hepatomegaly, jaundice, pancreatitis, cirrhosis.
Renal	Tubular and glomerular damage, oliguria, uremia.	Nephritic findings, proteinura.
Hematologic	Anaemia, thrombocytopenia.	Bone marrow hypoplasia, anaemia, leucopoenia, thrombocytopenia, impaired folate metabolism, basophilic stippling and karyorrhexis.
Cardiovascular	ST–T wave abnormalities, QT. Prolongation, ventricular fibrillation, atypical ventricular tachycardia.	Arrhythmias, pericarditis, acrocyanosis.
Respiratory	Pulmonary edema, ARDS, bronchial pneumonia, tracheobronchitis	Cough, pulmonary fibrosis, lung cancer.

Source: Das, Mallick and Sengupta (2003:422)

1.2 Arsenic guidelines and standards

According to the fourth edition of the WHO Guidelines for Drinking–Water Quality (2011) ***As*** is considered high–priority substance for screening in drinking–water sources. The current guideline value of 0.01 mg/L ***As*** was retained and designated as provisional since 1993. This value is higher in Bangladesh. According to the Guidelines for Environmental Assessment of Water Management (WRPO 2005) published by the Ministry of Water Resources the drinking water standard is 0.05 mg/L ***As***. This value was set in 1980 and it is equal to that established by the WHO in 1963. According to Rahman, Ravenscroft and Nishat (2003) if the Bangladesh standard were reduced from 0.05 to 0.01 mg/L ***As*** or lower, the affected population would be approximately doubled. The ***As*** content in drinking water of severely contaminated areas in Bangladesh is two or more times above the official limits.

1.3 Detection of Arsenic in Groundwater of Bangladesh

In 1990, a study carried out by the School of Environmental Studies of Jadavpur University in Kolkata (SOES) on groundwater in West Bengal (India) found that the southeastern parts of West Bengal near to Bangladesh Border areas are ***As***–contaminated. This resulted in suspicion about some southwestern regions of Bangladesh might be contaminated by ***As***. The Water and Sewerage Authority (WASA) is responsible for water supply and sewerage network in Dhaka city. The first analyses for ***As*** in Bangladesh were performed for three Dhaka WASA wells in 1990. Those tests did not detect the presence of any ***As***, and subsequent testing has shown that Dhaka's water supply remains free of ***As***. However, in 1993 the Department of Public Health Engineering (DPHE) collected 34 shallow tube-well water samples from Nawabanj and adjacent areas. The samples were tested for ***As*** at the Atomic Energy Commission, Dhaka. The ***As*** concentrations in 5 out of 34 samples ranged from 0.059 to 0.105 milligrams per litre (mg/L) in Shibganj Thana of Nawabanj district. Those tube-wells that were above the Bangladesh standard of 0.05 mg/l were sealed. Until 1994/95, generally accessible laboratories in Bangladesh were not equipped and staffed for the routine analysis of ***As*** in water. This is the principal reason for the scarcity of historical data on ***As*** levels in groundwater of Bangladesh (BCAS 1999).

Since ***As*** was detected in the groundwater of Bangladesh, various hypotheses were formulated to explain the origin of ***As***. Those included anthropogenic activities (the use of fertilisers, pesticides, insecticides, waste disposal, etc.) and geological causes. At the International Seminar on Arsenic and its Prevention organized by the Dhaka Community Hospital and SOES in Dhaka in February 1998 it was agreed that the contamination was of geological origin, not a man–made one. Between the geological origin hypotheses we can identify two as the most accepted. The pyrite oxidation hypothesis (proposed by the SOES group) explains that the ***As*** is released to the groundwater because of the oxidation of pyrite and/or arsenopyrite contained in the aquifer sands. The oxidation started by the lowering of the water table as a result of extraction for irrigation. Critics to this hypothesis state that if pyrite oxidation were happening, the same amount of sulphate along with ***As*** would be expected. However, ***As***–contaminated water in Bangladesh has low concentrations of sulphate. Critics also explain that there is no correlation between ***As*** occurrence and irrigation. Ravenscroft and Ahmed (1998), proposed the iron oxyhydroxide reduction hypothesis. It is based on the sedimentological history of the Bengal Basin. It explains that ***As*** is present in high concentrations in alluvial sediments of sand grains coated with iron hydroxide. Due to the drop in the sea level during the last glacial advance, rivers were incised about 130 metres below the present day base level initiating intensive erosion. The ***As***–contaminated sediments along with organic matter were deposited in the alluvial plains of the Bengal Basin when the stream base level was lowered. Following upraise in the sea level, these sediments stream submerged, the organic matter consumed oxygen and conditions changed from oxidising to reducing. The reducing conditions would lead to ***As*** solubilisation into groundwater provoking the current contamination of the aquifers (Ahmed 2003 and Hossain 2006).

1.4 Preliminary Research

In 2008, I started my research on arsenic contamination of groundwater in Bangladesh. I analysed four areas: in the south, Shahrasti (Chandpur) and Chatkhil (Noakhali) and in the north Nagarpur (Tangail) and Kaliganj (Gazipur). The groundwater in the northern areas is supposed to be free of arsenic while the south is severely contaminated. Nevertheless, toxic levels of ***As*** were found in rice and water samples collected in the northern areas. In Chandpur during the period 2006 – 2008, the United Nations Industrial Development Organization had an ***As***–mitigation program that offered water filters for free to some affected villages. The results of my research revealed that people did not filter their drinking water every day (on average they used their filters only 10 days per month) and they never use filtered water for cooking rice. Therefore, their daily intake of arsenic remains very high. At the same time it was detected that the water and food consumption patterns could increase the ***As***–exposure, especially among vulnerable groups as people living in food poverty and women. In order to refine the risk assessment, more scientific data are needed on ***As*** in foods, and on food and water consumption patterns. With limited technical capacity, the continuation of unsafe water consumption practices and the current agricultural practices, it can be expected that ***As*** in the food chain will further increase. This would hinder the current activities in the drinking–water sector to mitigate human ***As*** exposure (Heikens 2006).

1.5 Mitigation activities in Shahrasti Bangladesh

In response to the water arsenic contamination crisis, the Bangladeshi government, NGOs and UN agencies have implemented several programs of arsenicosis awareness and water arsenic removal in severely affected areas. Shahrasti is a sub-district located in the south east of the country. According to the Bangladesh Centre for Advanced Studies, in Shahrasti, 99% of the tube wells are ***As*** contaminated (BCAS 1999). The United Nations Industrial Development Organization (UNIDO) during the period 2006–2008 implemented a project in Shahrasti called "Improving Human Security by Mitigating Arsenic Poisoning" (UNIDO 2009). Part of the program consisted in distributing among the population Household Arsenic Removal Units (HARUs), and the installation of Community Based Arsenic Removal Units (CBARUs), as well as other awareness, prevention and treatment activities. This program had consequences on the attitude and behaviour of the population towards ***As***–contaminated groundwater and arsenicosis. During my fieldwork I found that in Shahrasti, HARUs and CBARUs provided by UNIDO were the most important technologies used for removing ***As***. On the other hand, more than 80% of the respondents responded affirmatively when they were asked if they know about arsenicosis.

2 Research questions

In the previous sections I discussed that Shahrasti is a severely contaminated area. Therefore, it is important to answer the first research question:

1. What is the economic cost of arsenicosis in the region?

A health production function approach was used in order to estimate the economic costs of arsenicosis. In Chapter 2, the predicted probability of observing arsenicosis patients in a household is estimated using a model for valuing the damages from arsenic contaminated water supplies. Then, this probability measure is used to derive treatment costs and the wage-loss arising from the illness.

On the other hand, I explained that people in Shahrasti received UNIDO's ARUs. Most of them are aware of the high arsenic content in the water and know about arsenicosis. Thus, the second research question is:

2. Why are they not using the ***As***–removal technologies on a daily basis?

In order to analyse the reasons for the low use of ***As***-removal technologies, I considered various possibilities that will be discussed in the following sections.

2.1 Household and *As*-removal technologies features

A basic explanation can be found in particular household features: for example, the distance from the household to the ***As***–removal unit. This case only applies for community based ***As***–removal units. We can expect that households located far away from CBARUs will not use them because of the short term high costs. In this sense, Pascual, Maddison, Field and Choudhury (2009) estimated how much a given risk of arsenicosis would have to be postponed to make that risk acceptable in ***As***–contaminated areas of rural Bangladesh and they found that household exposed to ***As***–contaminated water do trade-off risk against latency of developing arsenicosis. Another possibility is that the use of ***As***–removal technologies may be determined by the age of the household members. A lower use of ARUs could be expected if households members are relatively old or young. In contrast, a higher use of ***As*** filters can be expected if the head of the household has more years of schooling or higher level of income. It was expected that richer households would not use UNIDO filters because they are able to afford better arsenic removal technologies and ultimately ***As***-free water.

2.2 Time inconsistent preferences and the use of arsenic removal technologies

The scarce use of arsenic removal technologies despite having them available in the household or neighbourhood and the awareness of the risk of arsenicosis lead to the hypothesis that people in the affected areas exhibit time inconsistent preferences when making the intertemporal choice of using or not arsenic removal technologies. We must remember that skin lesions have between 5 to 20 years of latency from first exposure to visible sypmtoms. This long latency period may distort individuals' perception of the problem. According to O'Donoghue and Rabin (1999), individuals like to experience rewards soon and to delay costs until later. They explain that impatience is frequently captured by assuming that people discount streams of utility over time exponentially. Such preferences are time–consistent: a person's relative preference for wellbeing at an earlier date over a later date is the same no matter when she is asked. On the other hand, they identified what they called "present biased preferences." When considering trade–offs between two future moments, present biased preferences give stronger relative weight to the earlier moment, as it gets closer. They explain that inter-temporal choices involve *immediate costs* -where the costs of an action are immediate but any rewards are delayed -or *immediate rewards*- where the benefits of an action are immediate but any costs are delayed. By exploring these two different settings under the rubric of present biased preferences, they unify the investigation of phenomena like procrastination or overeating that come from the same underlying propensity for immediate gratification. In our case, the hypothesis is that people in the affected areas simply procrastinate in the use of ARUs.

2.4 Fieldwork

The fieldwork was designed to answer the research questions and to verify the different hypothesis. In the case of the estimation of the total economic cost of arsenicosis, surveys were employed to assess the relationship between the prevalence of arsenicosis at household level, the use of ***As***–removal technologies and household composition. Choice experiments were employed to determine if individuals have time inconsistent preferences and their risk preferences.

3. Structure of the First Section

The following chapters present the results of my research in Bangladesh. In Chapter 2 the economic costs of arsenicosis are estimated. Chapter 3 presents an assessment of the adoption of arsenic removal technologies using an experimental approach.

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Chapter 2

Estimating the Economic Cost of Arsenicosis in a Severely Contaminated Area of Bangladesh

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Abstract

The presence of inorganic arsenic at toxic levels in many aquifers of Bangladesh represents a serious health risk for people living in rural areas who rely on arsenic contaminated groundwater as their only source of drinking water. In this chapter, a health production function approach is used in order to estimate the economic costs of arsenicosis in rural households of Shahrasti, Bangladesh. The predicted probability of observing arsenicosis patients in a household is estimated using a model for valuing the damages from arsenic contaminated water supplies. Then, this probability measure is used to derive treatment costs and the wage-loss arising from the illness.

Keywords: Groundwater arsenic contamination, health production function, arsenic removal technologies, Bangladesh.

Introduction

In Bangladesh, the presence of inorganic arsenic at toxic levels in the aquifers represents a serious risk mainly for people living in rural areas that rely on arsenic contaminated groundwater as their only source of drinking water (Heikens 2006 and Alvarez and Uribe 2006). In response to the groundwater arsenic contamination crisis, the Bangladeshi government, NGOs and UN agencies have implemented several programs of arsenicosis awareness and arsenic removal in severely affected areas. Shahrasti is a sub–district in the south east of the country (see maps 1 and 2 in appendix A). The Bangladesh Water Supply Program Project–National Screening

Program determined that in Shahrasti 99% of the tube wells are arsenic contaminated (BCAS 1999). As a consequence, between 2006 and 2008 the United Nations Industrial Development Organization (UNIDO) had a project in Shahrasti called "Improving Human Security by Mitigating Arsenic Poisoning" (UNIDO 2009). Part of the program consisted in distributing among the local population 1,500 READ–F Household Arsenic Removal Units (HARUs), and the installation of 20 READ–F Community Based Arsenic Removal Units (CBARUs),[a] as well as other awareness, prevention and treatment activities (e.g. the installation billboards explaining how to recognise arsenicosis symptoms –see plate 5 in appendix B-).

Given the severity and prevalence of the arsenic contamination problem in Shahrasti, the main goal of this chapter is to estimate the economic costs of arsenicosis in the region. The costs of treatment (i.e. doctor fees, transportation and medication costs) and the opportunity cost of arsenicosis in terms of wage loss due to ill health are estimated for a representative household. The results provide valuable information that could be used to guide public policies and future investments.

It is evident that UNIDO's project had consequences on the attitude and behaviour of the population towards arsenic contaminated groundwater and arsenicosis. Households can invest time in order to avert the risk of arsenicosis by using arsenic removal technologies. Therefore, a health production function approach is deemed as the most appropriate tool in this context. The following research questions were posed:

a) What is the probability of observing arsenicosis patients in a household?

b) Which are the most important variables that influence the efficiency of the health production process? And

c) What is the cost of illness to a representative household?

The predicted probability of observing arsenicosis patients in a household is estimated using a model for valuing the damages from arsenic contaminated water supplies. Then, this probability measure is used to derive treatment costs and the wage-loss arising from the illness. It is expected that some important variables (e.g. knowledge of arsenicosis symptoms, water source, levels of income, education of the head of household, etc.) will have an important effect on the probability of having

[a] For a detailed description of the arsenic removal technologies see Appendix B.

arsenicosis patients in the household and on the probability of using arsenic removal technologies.

Although some other research papers have estimated the costs associated with arsenic exposure at household level (see for example Roy 2008 for the case of West Bengal and Khan 2007 for the case of Matlab and Laksman in Bangladesh), this paper focuses on a severely contaminated region where an important arsenic mitigation program was operating. This paper also contributes to the understanding of the most important variables that influence the efficiency of the health production process (specially the use of arsenic removal technologies). The paper is organised in the following way: section one reviews the literature on demand for health and averting behaviour. Section two presents the theoretical framework used in this chapter. The econometric estimation method is developed in section three. The use of arsenic-removal technologies in Shaharasti is discussed in section four. Section five presents the results of the econometric estimation. The final section discusses the results, offer policy recommendations and conclude.

1. Demand for health and averting behaviour

In his seminal paper "On the Concept of Health Capital and the Demand for Health" Grossman (1972) develops a model of demand for *good health*. In this model, agents are endowed with a stock of health that declines over time but, crucially, it can be increased by investment. Death eventually happens when the stock is exhausted. The level of health of an individual is not exogenous but depends on the resources allocated to its production. Thus, a household production function determines the investment in health capital and depends on environmental variables. The direct inputs in the function include the consumer's own time and market goods such as medical care, diet, exercise, etc. Grossman identifies the level of education of the producer as the most important variable that influences the efficiency of the production process. In this context, consumers demand health for two reasons. On the one hand, sick days are a source of disutility. On the other, as an investment commodity, it determines the total amount of time available for market and nonmarket activities. Thus, "an increase in the stock of health reduces the time lost from these activities, and the monetary value of this reduction is an index of the return to an investment in health" (Grossman 1972:225). Several other models built on Grossman's work and analysed different aspects of the health production function. Theoretical explanations of averting expenditures are also based on the household production function theory of consumer behaviour. Averting behaviour models assume that households produce consumption goods using different inputs that are subject to degradation by pollution. The household may respond to increased degradation of these inputs in various ways that are generally referred to as averting or defensive behaviours (Abdalla *et al* 1992). Cropper (1981) extended Grossman's model and explored the consequences of introducing a pollution variable in the health production function. The model was used to estimate willingness to pay for reductions (WTP) of sulphur dioxide in order to improve air quality and reduce related illnesses. Watson and Jaksch (1982) and Harford (1984), in studying the effect of air pollution on personal or household cleanliness, developed theoretical models considering the "price" of a cleaning episode as a function of pollution and cleaning frequency. Their models indicated the need for empirical results to test assumptions of cleanliness and averting expenditure behaviour. A common example of averting activity is filtering water before drinking it.

There are some studies concerned with water contamination in South Asia that use a health production function approach. For example, Dasgupta (2004) assessed health damages incurred by urban households reporting diarrhoeal illness in Delhi. The average total cost of illness for a representative household over 15 days during the peak period for diarrhoeal illness was estimated at Rs 71.43. This estimation includes the wage loss and costs of treatment for a household. Roy (2008), measured the economic costs imposed by arsenic related health problems in West Bengal. In order to estimate the benefits from a decline in arsenic concentration in ground water a household health production function model was used consisting of a household health production function and household demand function for mitigating and averting activities. The results indicate that reducing arsenic the concentration to the safe limit of 50 µg/l, a representative household will benefit by Rs 297 ($7) per month. An important antecedent for this paper is the work conducted by Khan (2007). He assessed the health impacts and costs related to arsenic contamination of groundwater in Matlab and Laksman sub-districts in Bangladesh. The results indicate that annual cost of illness to households is BDT 1056.82 ($17.91). In addition, it was found that wealthier households are more likely to avoid the incidence of conjunctivitis due to arsenicosis and to take additional mitigation actions to reduce the threat on their health.

Most of the Economics literature analysing the problem of groundwater arsenic contamination in Bangladesh has used non-market valuation techniques in order to assess WTP to access arsenic-free water. Ahmad *et al* (2003), used a contingent valuation methodology in order to estimate household preferences for different arsenic removal technologies and estimated WTP for piped water. They found that in Chandpur household's WTP for the service was BDT 50-75 per month and they are also willing to contribute BDT 2,000-3,000 towards the capital cost of piped water supply. Madajewicz *et al* (2007), estimated WTP for reducing ***As*** exposure by valuing an increase in the time spent walking towards an ***As***-free water source at an appropriate wage. However, they did not have data to estimate a household production function. The estimated WTP is BDT 90 per month. This result is quite close to the WTP found by Ahmed *et al* (2003). Nahar *et al* (2008) used the contingent valuation method in order to elicit willingness to pay for safe drinking water in three villages in Bangladesh. They found that households are willing to pay BDT 50 per month in order to access to ***As***-free water. Shafiquzzamanet *et al* (2009), found that only 30% of the households interviewed in Bagerhat, Bangladesh were willing to pay for a household filter. The stated amount was less than USD 5.

In a severely contaminated area, the economic costs posed by arsenicosis represent a huge burden to small communities, especially in rural and remote areas like the villages visited for this study. The estimation of such economic costs is therefore very important. In the following sections the theoretical framework and the econometric estimation methodology that will be used in this chapter are presented.

2. Theoretical framework

As discussed in the introduction, arsenic contamination of groundwater is a serious health hazard for the population living in Shahrasti. In view of this problem, UNIDO distributed and installed arsenic removal units in the area. Households that benefited from the project can invest time in order to avert the risk of arsenicosis by using the arsenic removal technologies at their disposal. In addition, households can also invest time or money in averting actions that give them access to arsenic-free drinking water (e.g. buying a water filter for private use). A health production function approach is thus appropriate in this case. In the context of the utility maximization theory, averting actions enter the health production function along with market goods consumed in the household. The individual's utility function is defined by

$$U = U(X, L, S) \qquad (1)$$

with

$$\frac{\partial U}{\partial X} > 0\,;\ \frac{\partial U}{\partial L} > 0\ ;\ \frac{\partial U}{\partial S} < 0$$

Where X denotes the household's expenditure on all non-health related goods normalized with a price of one. L represents leisure time per period and S corresponds to the time spent sick. The first order derivatives indicate that he household derives utility from the consumption of X and L but S yields disutility. The time an individual spends sick (S) is a function of the exposure to pollution due to arsenic (P) and the averting or defensive activities (D) in order to reduce the likelihood of illness (i.e. the use of an arsenic removal technology). The health production function can be written as:

$$S = S(P, D) \qquad (2)$$

where

$$\frac{\partial S}{\partial P} > 0; \frac{\partial S}{\partial D} < 0$$

Following Dasgupta (2004), S is defined as $S = S(Td, P)$ where Td represents the time used on averting activities. The following equation shows that the utility is maximized subject to the budget constraint:

$$I = I^* + w(T - L - Td - S(Td, P)) = X + p_d Td$$

or

$$I^* + wT = wL + wTd + wS(Td, P) + X + p_d Td \quad (3)$$

Where I^* represents non-wage income, w is the wage rate, T is the total time available X is the expenditure on all other goods, p_d is the price per unit of time spent on averting activities. In addition, $(T - L - Td - S(Td, P)) > 0$ under the assumption that all individuals work for a positive amount of time. In this case, the Lagrange multiplier associated with the time constraint (μ) in the first-order conditions takes a value of zero. The household's decision-making problem can then be defined by

$$\Lambda(X, L, S(Td, P), \lambda) = U\big(X, L, S(Td, P)\big)$$
$$+\lambda[I^* + w(T - L - Td - S(Td, P)) - X - p_d Td] \quad (4)$$

Where T represents the household's total time available and λ is the Lagrange multiplier for the household's income constraint. The first-order conditions are

$$\frac{\partial \Lambda}{\partial X} = U_X - \lambda = 0 \quad (5)$$

$$\frac{\partial \Lambda}{\partial L} = U_L - w\lambda - \mu = 0 \quad (6)$$

$$\frac{\partial \Lambda}{\partial Td} = U_S S_{Td} - w\lambda S_{Td} - w\lambda - \lambda p_d - \mu S_{Td} - \mu = 0 \quad (7)$$

$$\frac{\partial \Lambda}{\partial \lambda} = I^* + wT - wL - wTd - wS(Td, P) - X - p_d Td = 0 \quad (8)$$

The trade-off between labour and leisure is represented in equations (5) and (6). On the other hand, re-arranging equation (7) we obtain

$$U_S S_{Td}/\lambda - wS_{Td} - p_d = w \quad (9)$$

Re-arranging equation (5): $U_X = \lambda$ and substituting in (9) we obtain

$$U_S S_{Td}/U_X - wS_{Td} - p_d = w \qquad (10)$$

The term $U_S S_{Td}/U_X$, gives the marginal rate of substitution between *Td* and *X*., Since it is assumed that S_{Td} is negative, the second term, $-wS_{Td}$, is positive (given that $w > 0$). As the time spent on defensive activities increases the sick time decreases. Thus, $-wS_{Td}$ gives the gain due to reduced sick time, valued at the wage rate. Therefore $(U_S S_{Td}/U_X - wS_{Td})$ denotes the gross gain from an increase in *Td*. The expense incurred for defensive activities is represented in the third term $(-p_d)$. The net gain from a unit increase in *Td* is represented in the right-hand side of the optimality condition. The wage loss (*w*) resulting from a unit increase in time spent on defensive activities should be equal to the net gains from such increase.

3. Econometric estimation method

The utility maximization problem described in the previous section provides the first-order conditions that would solve for an optimal defensive behaviour described by

$$Td^* = Td^*(w, p_d, I, P) \qquad (11)$$

The time spent sick can be obtained by substituting Td^* in *S*

$$S = S(Td^*, P) \qquad (12)$$

The model provides the theoretical basis for an empirical model which can estimate equations (11) and (12) and assess how individuals respond to the threat of arsenic contamination and arsenicosis. The empirical model considers health and defensive behaviour as interlinked variables. The procedure requires the estimation of a relationship between illness and arsenic contamination while controlling for other variables affecting health status using cross-section data on illness and defensive behaviour. In the estimation of the health production function controls for other determinants of health status (e.g. physical and socio-economic features) are included. Binary dependent variables are used in the specification of these equations. It is assumed that households show defensive behaviour if a random variable y_1^* takes a value greater than zero. On the other hand, y_1^* would be determined by individual/household characteristics (including income and costs of defensive behaviour) and some risk factors (e.g. the presence of arsenic in the household's water source). A vector of explanatory variables (x_1) summarizes these observable variables. Other risk factors that determine the household's defensive behaviour but were not included in the survey are taken into account in a variable R^*. Such factors may include, for example, variations in arsenic concentrations in the source of drinking water that were not identified during the testing process, previous experience of illness, etc. In this way, the equation for defensive behaviour can be written as

$$y_1^* = \beta_1 x_1 + \gamma_1 R^* + \varepsilon \qquad (13)$$

where ε is a random error term. It is assumed that the coefficient γ_1 is positive, that is a higher value of R^*, is associated with higher risk of arsenicosis and hence a higher level of defensive activities. Binary dependent variable techniques can be used in the estimation of equation (13). A binary specification is assumed for the second reduced-form equation where a random variable y_2^*, defined as

$$y_2^* = \beta_2 x_2 + \gamma_2 R^* + \delta y_1^* + \eta \ (14)$$

y_2^* takes on a value greater than zero if arsenicosis is observed in a household. Here x_2 is also a set of individual characteristics and sources of risk for arsenicosis (e.g. contamination of drinking water, awareness of arsenicosis and its symptoms) that are available to the researcher. The determinants of illness include unobservable risk factors R^*. Here γ_2 is positive and implies that the higher the risk of contamination the higher the likelihood of developing the disease. Arsenicosis is controlled by defensive behaviour y_1^*, so that the coefficient δ should be negative. A binary choice model can be used to estimate equation (14). It is assumed that the error terms ε and

η are independent of each other. The risk factors are included in the error terms because they are unobservable

$$v_1 = \gamma_1 R^* + \varepsilon \;\; and \; v_2 = \gamma_1 R^* + \eta$$

A probit regression of observed defensive behaviour produces consistent estimates under the assumption that x_1 is independent of the error v_1. Nevertheless, a probit regression of arsenic related illness on individual characteristics and defensive behaviour would produce inconsistent estimates. This can be explained pointing to the hidden risk factors. A correlation between the defensive behaviour and the error term v_2 in the illness equation can be expected. Therefore, correct procedure is proposed. Equation (13) is presented in reduced form since it contains only exogenous regressors. A second reduced-form equation is obtained when equation (13) is substituted into (14). Here, defensive behaviour is eliminated from the regressors and arsenicosis depends only on individual or household characteristics and unobservable risk

$$y_2^* = \beta_2 x_2 + (\delta\beta_1)x_1 + [\,(\delta\gamma_1 + \gamma_2)R^* + (\delta\varepsilon + \eta)\,](15)$$

The error term in the first equation, $v_1 = \gamma_1 R^* + \varepsilon$, is correlated with the error term of equation (15). The covariance between the error terms of the reduced-form equations, (13) and (15), is equal to $(\delta\gamma_1 + \gamma_2)\gamma_1 V(R^*) + \delta\sigma_2\varepsilon$, and is in general non-zero. This implies that the probability of becoming ill is not independent of engaging in defensive behaviour. The net effect on illness of a change in the unobservable risk (after the individual's defensive actions) can be represented in the term $(\delta\gamma_1 + \gamma_2)$. Since the probabilities of defensive behaviour and illness are non-independent, equations (13) and (15) are jointly estimated as a bivariate probit model. Such estimation would imply the assumption that v_1 and v_2 are (jointly) normally distributed, and tend to behave reasonably well. In such case, the estimates for the coefficients would be consistent. In addition, 'robust' standard errors can be obtained using the information matrix (*I*) and the matrix of cross products of the first derivatives of the log likelihood function (*F*) (i.e. the matrix: $\Gamma^{1}F\,\Gamma^{-1}$). Also note that the parameters cannot all be identified separately. The bivariate Probit estimation would lead to estimates of the ratios $\hat{\beta}_1 = \beta_1/\sigma_1$ and $\hat{\beta}_2 = \beta_2/\sigma_2$, where σ_1 and σ_2 represent the standard deviations of the reduced-form error terms. Here σ_1 and σ_2 cannot be identified, nor can the two γ and δ. In summary, the econometric model has two equations of the form:

$$z_{i1} = \beta_1^{'} x_{i1} + \varepsilon_{i1}{'} \qquad y_{i1} = 1 \;\; if \;\; z_{i1} > 0$$
$$y_{i1} = 0 \;\; \text{otherwise}$$
$$z_{i2} = \beta_2^{'} x_{i2} + \varepsilon_{i2}{'} \qquad y_{i2} = 1 \;\; if \;\; z_{i2} > 0$$
$$y_{i2} = 0 \;\; \text{otherwise}$$
$$(\varepsilon_{i1}, \varepsilon_{i2}) \sim \text{bivariate normal } [0, 0, 1, 1, \rho]$$

The parameters for this model can be estimated using a complete sample on (y_1, y_2, x_1, x_2).

4. Use of arsenic removal technologies in Shahrasti

In 2008 fieldwork was conducted in order to understand water consumption patterns among the population in Shahrasti.[b] A question about the use of filters for drinking and cooking water was done. Six kinds of arsenic filters were offered as possible alternatives as well as the possibility of using other kind of filter or purification system. In Shahrasti, among the population using arsenic removal technologies 50% used CBARUs, 43% used HARUs, and the rest used other technologies. Nevertheless, during the visits to different households in the affected areas the interviewees confessed that although they had an ARU they did not use it every day. Therefore, in a complementary survey it was asked how many days a month did they actually use the filters. It was found that the respondents did not use their ARUs daily. On average they used the filters 11.5 days. On the other hand, 86% of the respondents responded affirmatively when they were asked if they know about arsenicosis. Nevertheless, only 46% of the respondents could identify the arsenicosis symptoms. A follow up study was carried out in September 2010. Four hundred surveys were applied in the same villages that were visited in 2008 and water was

[b] For further details see Dávila (2008).

collected from CBARUs in order to conduct a test for arsenic in a certified laboratory at the University of Dhaka.[c] This follow up study brought to light several problems associated with the adoption of HARUs and CBARUs. First, the water samples taken from CBARUs in the villages of Voldigi and Dehala showed arsenic concentration levels far above the Bangladeshi guideline value for arsenic content in drinking water (0.05 mg/L) (see the results in Appendix C). Second, the CBARUs located in the villages of Khonossore, Podua and Isapura presented mechanical problems at the moment (some pieces were damaged and I was informed that they were not available in the local stores). It was impossible to collect water samples for analysis from these CBARUs and the villagers were not able to collect water from them. Furthermore, the villagers informed that in all cases the CBARUs stopped working 6 months before our visit and the people in those areas were forced to collect water from other sources (mainly hand tube-wells that in most cases present toxic arsenic levels). This is clearly an important health issue, particularly as villagers are using water from the CBARUs under the impression that they provide ***As***-free water. In relation to the CBARUs' water features, the survey revealed that 98% of the interviewees think that it is worth collecting their drinking water from a CBARU. Further, 98% of the respondents like the taste of the CBARUs water, 88% liked its colour and 87% its smell. A letter was sent to the UNIDO's office in Bangladesh informing about all the problems found during the fieldwork (see Appendix D). On the other hand, it was found that among the population using arsenic removal technologies only 3% of the respondents used UNIDO HARUs (down from 43% in 2008). Also, 79% of the interviewees stated that they used UNIDO CBARUs (29% more than in 2008). Most of the villagers stated that they preferred the use of CBARUs to HARUs. During the follow up study it was found that only three households in the sample kept HARUs but they were not using them and they were not serviced (see plate 2 in appendix B). Further, during an interview with the local UNIDO officer he confirmed that the adoption of HARUs was not successful. On the other hand, some households use privately owned water filters (see plate 6 in appendix B). These filters are quite popular. However, not all of them remove arsenic (commercial filters usually remove bacteria only). This is another latent problem since in the interviews the people told us that they are sold as arsenic filters.

[c] The test was conducted at the Bangladesh – Australia Centre for Environmental Research of the Department of Soil, Water and Environment.

5. Data collection and analysis

Data were obtained from a survey conducted in Shahrasti, Chandpur after a preliminary visit to the study site in 2010. A random and stratified sample of 300 households was used. These households were selected from the set of villages previously visited in order to collect data on adoption of arsenic removal technologies and household characteristics. Three MSc students at the University of Dhaka were hired as research assistants. Only individuals 18 years old or above were interviewed, preferably the head of household or a mature respondent if the head of household was not present during the visit. Table 1 shows the average profile of sampled households. The respondents' average age is 36.73 years and 52.72% of them are female. An average household has 6.2 members and there are two children less than 14 years. The average per capita income per household is 2,438.

Table 1 Average profile of sampled households

Description	Mean	SD	[95% Conf. Interval]	
Age of the respondent (in years)	36.73	0.78	35.19	38.27
Percentage of female respondents	52.72	2.92	46.97	58.40
Number of household members	6.20	0.14	5.92	6.49
Number of children (under 14) in the household	1.95	0.08	1.80	2.10
Per capita income (BDT per month)*	2,438.23	141.93	2,158.90	2,717.55

* 1 USD = 81.96 BDT (2012 average)

Table 2 presents additional analysis of the socio-economic information collected. The households' income has been divided into quintiles. Households in the first quintile have a monthly income per capita equal to or less than BDT 1,000. 26% of the surveyed households fall into this quintile. On the other hand, 17% of the households are in the higher income category (quintile 5) and have a monthly income per capita higher than BDT 3,500. The respondents' average educational attainment (measured in years of schooling) rises with income level. Respondents in the first quintile have on average 3.36 years of schooling while respondents in the fifth quintile have 6.26 years of schooling on average. The reported average family size is 7.49 members in the first income quintile and 4.86 in the fifth income quintile. The average number of children under 14 in the household is 2.45 in the first income quintile and 1.53 in the fifth income quintile. In other words, better off households have on average a smaller family size and fewer children.

Table 2 Socio-economic information of the surveyed households

Income quintiles	Monthly income per capita range in BDT*	Percentage of households	Education (years of schooling)		Family size		Children Under 14	
			Mean	SD	Mean	SD	Mean	SD
1	0-1,000	26%	3.36	2.55	7.49	2.03	2.45	1.06
2	1,000-1,400	15%	4.05	2.57	5.86	1.55	2.05	1.15
3	1,400-2,000	22%	4.98	3.33	6.11	2.57	1.79	1.06
4	2,000-3,500	20%	5.64	3.48	6.07	3.14	1.72	1.60
5	3,500 and above	17%	6.26	3.88	4.86	1.86	1.53	1.23
* 1 USD = 81.96 BDT (2012 average)			1.1	1.2	1.3	1.4	1.5	1.6

Table 3 shows that 72 households (out of 294) have arsenicosis patients (i.e. around 25% of all the households surveyed). A third of the households reporting patients are in the lowest income category. It is interesting to note that only 7 households (out of 50) in the highest income category have arsenicosis patients.

Table 3 Households that have arsenicosis patients (by income category)

Arsenicosis Patients	Income quintiles 1	2	3	4	5	Total
No	51	30	52	46	43	222
Yes	24	13	14	14	7	72
Total	75	43	66	60	50	294

On the other hand, Table 4 presents the number of cases in households that have arsenicosis patients. The survey identified households suffering arsenicosis by direct questioning of the head of the household and the observations of the enumerators who had undergone preliminary training. The enumerators were instructed to inspect the hand palms of the interviewees and family members in order to identify undiagnosed cases of arsenicosis. It can be observed that the lowest category of income has the highest number of arsenicosis cases (more than 20). In contrast, the highest category of income only has 6 cases. A negative and statistically significant correlation coefficient between the number of cases reported and the household's level of income was found ($r = -0.1725$, $p = 0.0030$).

Table 4 Number of cases in households that have arsenicosis patients (by income category)

Number of cases	Income quintiles 1	2	3	4	5	Total
1	18	10	10	11	4	53
2	2	3	4	0	1	10
More than 3	2	0	0	0	0	2

In total 85 arsenicosis cases were reported (see Table 5). It should be noted that the number of female patients is higher in most of the income categories and especially in households with lower levels of income. The number of cases reported (both male and female) is higher in the first income quintile. It should be noted that according to the respondents not all the patients receive medical attention. Around a third of the arsenicosis cases in first quintile of income do not go to the doctor for treatment.

Table 5 Number of cases reported and receiving medical attention by gender and income category

Income quintiles	Female		Male		Both	
	Cases reported	Receive med. att.	Cases reported	Receive med. att.	Cases reported	Receive med. att.
1	24	16	10	6	34	22
2	9	7	7	4	16	11
3	13	9	5	4	18	13
4	3	3	8	6	11	9
5	3	1	3	1	6	2
Total	52	36	33	21	85	57

The most important ***As***-exposure factor is the consumption of ***As***-contaminated groundwater. If the main source of drinking water is a hand tube-well this can be considered a risk factor since the Bangladesh Centre for Advanced Studies determined that in Shahrasti, 99% of the hand tube-wells are contaminated with arsenic (BCAS 1999). Table 6 shows that for 76% of the households surveyed the main source of drinking water is a hand tube-well. The reasons for using a hand tube-well as the main source of drinking water are described in Table 7. Around 20% of the respondents mentioned that they never use a hand tube-well. 27% mentioned that a clean source is far from their home and 32% considered that there were no other options available for their households. 12% of the respondents consider that their hand tube-wells are not contaminated.

Table 6 Main source of drinking water

Main DW source	Freq.	Percent	Cum.
HTW	223	75.85	75.85
Other	71	24.15	100
Total	294	100	

Table 7 Reasons for using a HTW

Reason	Freq.	Percent	Cum.
Never use a HTW	61	20.75	20.75
Clean source far from home	81	27.55	48.3
No other option	94	31.97	80.27
HTW not contaminated	35	11.9	92.18
Other	23	7.82	100
Total	294	100	

Households were asked about their use of filters. Table 8 shows that around 50% of the households do not use any kind of water filters. In addition, the use of privately owned filters is higher among households with higher levels of income and the use of CBARUs is higher among households with lower levels of income. A positive and statistically significant correlation coefficient between the use of a private filter and the household's level of income was found ($r = 0.2064$, $p = 0.0004$). In contrast, there is a negative and statistically significant correlation coefficient between the use of a CBARU and the household's level of income ($r = -0.1717$, $p = 0.0034$).

Table 8 Number of households using water filters (by income category)

Income quintiles	Uses private filter		Total
	No	**Yes**	
1	71	3	74
2	41	1	42
3	59	6	65
4	54	5	59
5	38	12	50
Total	263	27	290
Income quintiles	**Uses CBARU**		
	No	**Yes**	**Total**
1	31	43	74
2	19	23	42
3	32	33	65
4	34	24	58
5	33	17	50
Total	149	140	289

On average, the respondents reported that the distance to the CBARU is 16 minutes walking away from their household. 144 respondents (46%) consider that the

CBARU is far from their house, 112 respondents (38%) stated the CBARU is not far from their house and 38 respondents (12%) did not know or did not answer. Then, they were asked if they would go more often to the CBARU if it was closer to their household and 74% responded affirmatively. Of those who responded affirmatively, they stated that on average they are willing to walk 3.18 minutes away from their household in order to collect ***As***-free drinking water (see Table 9). This figure is close to the results found by Nahar *et al* (2008) in three villages of Bangladesh. They established that female head of households are willing to walk 3.88 minutes in Ranihati, 4.6 minutes in Rajarampur and 3.74 in Mianpur.

Table 9 Distance to the CBARU

Description	Mean	SD	[95% Conf. Interval]	
Stated distance	16.04	0.92	14.23	17.85
Desired distance	3.18	0.17	2.85	3.51

6. Results of the econometric estimation

Table 10 describes the variables used in the econometric estimation. The dependent variable for equation (1) in all models is arsenicosis patients (Patients). It takes a value of one if the household has at least one arsenicosis patient and zero otherwise. For equation (2), the dependent variable is the use of arsenic removal units. Groundwater filtration is the most important defensive behaviour against arsenicosis. It is important to analyse the differences between the use of private filters and CBARUs. Therefore, the independent variable in equation (2) takes a value of 1 if the household reports the use of a filter (private filter or CBARU) and zero otherwise. The first group of explanatory variables corresponds to the socio-economic characteristics of the respondent. The variables considered are the age (Age), gender (Gender), and educational attainment (Education) of the respondents as well as the five categories of the household's monthly income per capita as described in **Table 2** (Income). The family size (FamSize) is also included. Different studies on the health production function use household-level information after controlling for family size in the estimation (see for example Dasgupta 2004 and Roy 2008). The reason is that individual-level information especially on defensive activities is often a household-level decision. Location dummy variables were included in order to capture regional fixed effects. The second group of explanatory variables describes risk factors. The first risk factor considered is the main source of drinking water. This variable takes the value of one if the main source is a hand tube-well (DrinksHTW) and zero otherwise. A second risk factor is the awareness (or not) of arsenicosis and its symptoms. It is expected that if the head of the household is aware of arsenicosis and its symptoms he or she will exhibit arsenicosis averting behaviour (i.e. the use of a private filter or a CBARU). The stated distance to the CBARU (in minutes walked) was also included. It can be expected a negative relationship between the use of a CBARU and its distance from the household and a positive relationship between the use of a private filter and the distance to the CBARU.

Table 10 Definition of Variables

Variable	Definition
Patients	Reports arsenicosis patients in her family (1=Yes, 0=No)
Filter	The household uses a private filter (1=Yes, 0=No)
CBARU	The household uses a CBARU (1=Yes, 0=No)
Age	Respondent's age (in years)
Education	Respondents education (in years)
Gender	Respondents gender (1=Female, 0=Male)
FamSize	Family Size (number of household members)
Income	Monthly income per capita quintiles
Location	Dummy variables for each village: Khonosore, Isapura, Voldigui and Chototula
DrinksHTW	Main source of drinking water is a hand tube-well (1=Yes, 0=No)
KnowSympt	Respondent knows Arsenicosis symptoms (1=Yes, 0=No)
Distance	Distance to CBARU (minutes walked)
EduGen	Interaction between age and education
EduInc	Interaction between education and income

Table 11 and **Table 12** present the results of the estimated models for respondents using a private filter or a CBARU respectively. Model 1 is a simple model that excludes regional effects and interaction terms. Model 2 includes location dummies in order to capture regional effects. Model 3 includes location dummies and interaction variables between education and gender (EduGen) and education and income (EduInc). The results for the first equation in all models show that respondents with higher levels of education are less likely to have arsenicosis patients in the household. As predicted by Grossman (1972), the level of education appears as one of the most important variables that influence the efficiency of the health production process. The interaction term between income and education is significant. Once the interaction term is included, it can be observed that respondents with higher income and higher levels of education are less likely to have arsenicosis

patients. Respondents from Chototula are more likely to have arsenicosis patients while respondents from Isapura are less likely to have arsenicosis patients when the interaction terms are included. The respondent's age, gender, family size, other regional variables and the interaction between education and gender are not significant. In the case of respondents using a private filter, it can be observed that respondents with higher levels of education and higher income are more likely to use a private filter (models 1 and 2). The interaction term between income and education is significant when it is included. Households located in Khonosore and Isapura are less likely to use private filters.

In the case of respondents using a CBARU, it can be observed that respondents with higher levels of education (all models) and higher levels of income (model 1 and model 3) are less likely to use a CBARU. In contrast with the results of private filter users, households located in Khonosore and Isapura are more likely to use a CBARU. It is interesting to note that households in Chototula are less likely to use CBARUs and more likely to have patients. On the other hand, households located in Isapura are less likely to have arsenicosis patients and more likely to use CBARUs. A household is less likely to use a CBARU if its main source of drinking water is a hand tube-well (models 2 and 3). As expected, households reporting a longer distance to the CBARU are less likely to use it. Finally, it should be noted that knowing the arsenicosis symptoms increases the likelihood of using a CBARU (models 2 and 3). This could be a result of the arsenicosis awareness campaigns that UNIDO conducted in the area.

Table 11 Estimated bivariate probit regression models (private filter)

Equation 1: dep. var. = Patients	Model 1	Model 2	Model 3
Ind. Var.	Coeff.	Coeff.	Coeff.
Age	-0.0009	0.0005	-0.0016
Education	-0.1948*	-0.2071**	-0.6744***
Gender	-0.1647	-0.1304	-0.1172
FamSize	0.0025	-0.0004	-0.0043
Income	-0.0917	-0.0859	-0.2920**
DrinksHTW	-0.2886	0.0165	0.0129
KnowSympt	0.1226	0.0426	0.0197
Khonosore		0.1809	0.1647
Isapura		-0.5031	-0.5905*
Voldigi		0.3496	0.3232
Chototula		0.4362*	0.4276*
EduGen			-0.0004
EduInc			0.1440**
_cons	0.0748	-0.3011	0.4239
Equation 2: dep. var. = Use private filter			
Ind. Var.	Coeff.	Coeff.	Coeff.
Age	0.0132	0.0142	0.0144
Education	0.3070**	0.3312**	-0.456
Gender	0.3235	0.4263	0.1014
FamSize	0.0669	0.0481	0.0474
Income	0.2099**	0.2026*	-0.1099
DrinksHTW	-0.1191	-0.0382	-0.0051
KnowSympt	0.4197	0.3925	0.3813
Distance	-0.0028	0.004	0.0023
Khonosore		-1.0074**	-1.0363**
Isapura		-0.8652**	-0.9337**
Voldigi		-0.7555	-0.8201
Chototula		-0.2916	-0.2834
EduGen			0.2324
EduInc			0.1984*
_cons	-3.8584***	-3.5624***	-2.4454**
athrho _cons	-0.0877	-0.0508	-0.093
Statistics			
N	294	294	294
ll	-225.4305	-215.6291	-210.9476
df_m	15	23	27
chi2	31.6133	51.216	60.5791

legend: * p<.1;** p<.05;
***p<.01

Table 12 Estimated bivariate probit regression models (CBARU)

Equation 1: dep. var. = Patients	**Model 1**	**Model 2**	**Model 3**
Ind. Var.	Coeff.	Coeff.	Coeff.
Age	-0.001	0.00003	-0.0019
Education	-0.1934*	-0.2094**	-0.6716***
Gender	-0.1651	-0.1361	-0.1095
FamSize	0.0033	0.0027	-0.0018
Income	-0.091	-0.0834	-0.2890**
DrinksHTW	-0.2846	0.0211	0.0186
KnowSympt	0.1198	0.0366	0.0127
Khonosore		0.1958	0.1815
Isapura		-0.5014	-0.5872*
Voldigi		0.3445	0.3201
Chototula		0.4400*	0.4345*
EduGen			-0.0081
EduInc			0.1433**
_cons	0.0684	-0.3077	0.4069
Equation 2: dep. var. = Use CBARU			
Ind. Var.	Coeff.	Coeff.	Coeff.
Age	0.0027	0.0016	0.0007
Education	-0.2194**	-0.2949**	-0.5939**
Gender	0.1215	-0.0057	-0.0242
FamSize	-0.05	-0.0275	-0.0287
Income	-0.1159*	-0.1133	-0.2495*
DrinksHTW	0.1144	-0.7373***	-0.7440***
KnowSympt	0.1839	0.4542*	0.4458*
Distance	-0.0286***	-0.0336***	-0.0352***
Khonosore		0.6409**	0.6636**
Isapura		1.2208***	1.2332***
Voldigi		0.1859	0.1993
Chototula		-0.7243**	-0.7318***
EduGen			0.0118
EduInc			0.0893
_cons	1.0797**	1.5528**	2.0331***
athrho _cons	0.1019	0.2283*	0.1961
Statistics			
N	294	294	294
ll	-318.3656	-286.8583	-283.6064
df_m	15	23	27
chi2	49.2907	112.3053	118.8092

legend: * p<.1;** p<.05; ***p<.01

The results of Model 3 are used to estimate the predicted probability of a household having arsenicosis patients. The univariate (marginal) predicted probability of success in having arsenicosis patients is 0.24409 for CBARU users and 0.24398 for private filter users. The average monthly cost of treatment (*c*) for affected households paying for private health services is BDT 1,083. This is calculated as the average doctor fee (BDT 222), plus the average transport costs (BDT 451) plus the average medical expenditure for treating mild to moderate arsenicosis (BDT 410 or USD 5) per month. The treatment generally lasts from three to six months (World Bank 2005). If the probability of a household being affected (λ) is assumed at 0.244 and given the average size (s) of the family is 6.2, the cost of treatment for a representative household (C) can be derived using the following equation:

$$C = \lambda \cdot s \cdot c \qquad (16)$$

Therefore, the average cost for a representative household accessing private health services is BDT 1,638. The average monthly household income is BDT 13,123. Payments for private health services represent 12.5% of the average monthly household income. However, only 14 households (around 5% of the sample) reported taking arsenicosis patients to private health services. The rest of the households reported having access to free health services provided by the government. These households would have to pay transportation costs only. In this case, the average cost for a representative household is BDT 682.

The opportunity cost of arsenicosis includes the costs of treatment and the implied wage loss, arising from days lost due to ill health. The estimated probability of illness (λ) is multiplied by the average number of sick days lost to illnesses relating to arsenic poisoning (n), the average wage rate in agriculture (w), the rate of employment in agriculture in the area (rt), and finally the average size of the household (s), in order to arrive at the total wage loss (W) for a period of 5.29 days, for the representative household. Table 13 presents the computations for the wage loss. Finally, the total cost of illness is the Wage loss (BDT 962.33) plus the private cost of treatment (BDT 1,638). The estimated total cost of illness is BDT 2,600.

Table 13 Wage loss due to arsenic related illness

Variable name	Value
λ (probability of a household being affected)	0.244
Average family size (s)	6.2
Average number of sick days lost to illnesses relating to chronic arsenic poisoning [a] (n)	5.29
Rate of employment in the agricultural sector [b] (rt)	0.481
Average daily wage-rate of Agricultural labour in BDT [c] (w)	250
Wage-loss for a representative household: $W = \lambda \times s \times n \times rt \times w$	962.33

[a] *Source: Khan (2007:7)*
[b] *Source: UN World Statistics Pocketbook*
[c] *Source: Bangladesh Bureau of Statistics (BBS)*

7. Discussion and conclusions

The aim of this chapter was to estimate the probability of observing arsenicosis patients in a household using a health production function approach and to assess the cost of illness to a representative household. The econometric results show that the levels of education and income are the most important predictors of arsenicosis patients in a household. More affluent and educated households are less likely to have arsenicosis patients. Better-off households have a greater capacity to adopt additional defensive behaviour through the use of private filters. In relation to UNIDO's program, it should be said that it has had mixed results. The use of a CBARU is the most important defensive behaviour among households with lower levels of education and income. It is interesting to note that respondents that know the arsenicosis symptoms are more likely to use a CBARU. It is evident that the awareness campaign in the region had a positive effect on the adoption of CBARUs among the local population. Another important result refers to the regional differences. Households in Isapura are less likely to have arsenicosis patients and at the same time are more likely to use a CBARU. In contrast, households in Chototula are more likely to have arsenicosis patients and less likely to use a CBARU. Using the econometric results, it was estimated that the predicted probability of success in having arsenicosis patients in a household is 0.244. In addition, the average cost for a representative household of accessing private health services is BDT 1,638. This quantity represents half the monthly income of an average household. The total cost of illness was estimated at BDT 2,600. This represents a huge burden for poorer households and is above the total monthly income of households in the first three quintiles. It was found that although there are free medical services provided by the state one third of the cases reported do not receive medical attention. In consequence, the adoption of arsenic removal technologies is crucial especially for poorer households. The adoption of community based arsenic removal technologies in the region was successful up to some point. As mentioned in section 3, it was found that 79% of the interviewees stated that they used UNIDO CBARUs (at least up to the date when the CBARUs stopped working). Further, it was found that 98% think that it is worth collecting their drinking water from a CBARU. Also important is that most of the respondents like the taste, colour and smell of the water they get from the CBARUs. Nevertheless, it is very unfortunate to report that during the last visit to the area in summer 2012 it was found that none of UNIDO's CBARUs were working. Hand-pumps and water taps were stolen and nobody was sent to service them (see plate 4 in Appendix B). The fact that none of the CBARUs were operating properly prompted a reversal to the consumption of ***As*** contaminated groundwater from hand tube-wells. It should also be noted that even if the CBARUs are fixed but not properly serviced will have a negative health impact (because the villagers use water from the CBARUs under the impression that they provide uncontaminated water). The BCSIR stated that post–deployment performance monitoring of READ-F technologies was a necessary condition for its deployment (BCSIR 2003). UNIDO deployed 1,500 READ–F HARUs and 20 READ–F CBARUs in the area (UNIDO 2009). However, all post–deployment performance monitoring activities stopped in 2011. It is fair to say that the adoption of household based arsenic removal units was unsuccessful. In 2010 only 3% of the respondents used UNIDO HARUs down from 43% in 2008. Besides, most of the villagers stated that they preferred the use of CBARUs over HARUs.

It is considered that future policies should be aimed mainly at promoting the use of community based arsenic removal technologies. Finally, despite the fact that some households use privately owned water filters it should be noted that not all of them remove arsenic. In the interviews the people explained even bacteria filters are sold as arsenic filters. Thus, there is an urgent need of regulation of the market of water filters to provide private consumers with genuine arsenic removal technologies.

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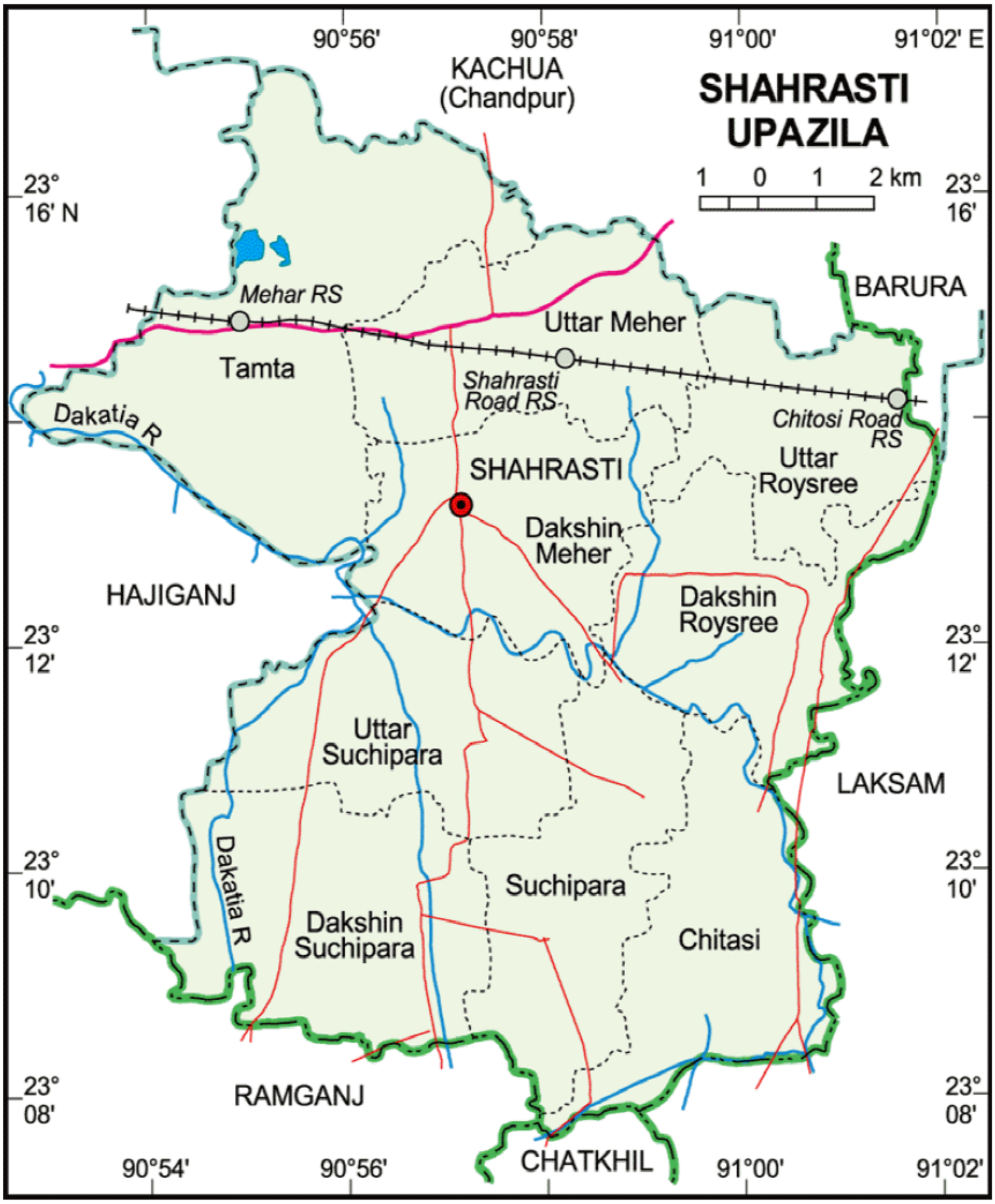
Appendix A Maps

Map 1 Location of Shahrasti in Bangladesh

Source: Google maps

Map 2 Shahrasti Upazila



Source: GIS Section, BANGLAPEDIA, Asiatic Society of Bangladesh.

Appendix B READ-F Arsenic Removal Technologies

In the literature about ***As***–removal technologies it is widely acknowledged that ***As*** can be removed from water by filtration through sorptive media. Its efficiency depends on the use of oxidizing agents to aid ***As*** sorption. Such media will eventually saturate with ***As*** particles removed from water. This implies that the media has to be periodically regenerated. Cerium oxide (CeO_2) has been used as sorptive media to remove ***As*** from water (Visoottiviseth and Ahmed 2008). UNIDO's units use sorptive filtration for ***As***–removal. The technology employed is READ–F. This is a proprietary adsorbent produced by Brota Services International, Bangladesh and Nihon Kaisui Co. Ltd, Japan. In 2003, the performance statement of READ–F was tested and verified as part of the Environmental Technology Verification – Arsenic Mitigation (ETV–AM) Program. The tests were conducted in five regions: Hajiganj, Bera, Manikganj, Nawabganj and Faridpur. The Bangladesh Council of Scientific and Industrial Research (BCSIR) carried out the verification in association with the Ontario Centre for Environmental Technology Advancement (OCETA) and an expert group designated by the government of Bangladesh. The technology was permitted to be sold provisionally in Bangladesh for a period of two years. READ–F adsorbs both arsenite and arsenate. This technology does not require pH adjustment before or after treatment and the oxidation of arsenite to arsenate is not necessary.

READ–F is composed of hydrous cerium oxide ($CeO_2 \cdot nH_2O$) acting as the adsorbent and an ethylene–vinyl alcohol copolymer (EVOH). It contains 60% water, with a 0.7–mm average particle size and a 1.6 g/ml specific weight. It is not classified as a hazardous material and it does not contain organic solvents or other volatile substances. The units also remove iron by sand filtration. The household *As*–removal unit operates like conventional filters with downward water flow. It has sand and resin beds arranged in one container; in the community unit these two beds exist separately (Visoottiviseth and Ahmed 2008:97). In order to regenerate the media, sodium hydroxide (NaOH) and sodium hypochlorite (NaClO) should be added and then rinsed with water. Before reuse, the regenerated READ–F requires neutralization by hydrochloric acid (ClH) and further washing with water (World Bank 2005). The BCSIR conducted an *As* analysis (Toxicity Characteristic Leaching Procedure and Total Available Leaching Procedure tests) on a homogeneous sample of the exhausted READ–F media. The results of the analysis showed that the total *As* concentration in the leachate was 7 μg/L. Therefore, by US–EPA standards, the waste was not classified as hazardous. It should be noted that the provisional verification statements produced by the BCSIR are based on proper installation, maintenance, media storage and operation. In Bera, Manikganj, Nawabganj and Faridpur READ–F met the proponent's claim for media life. However, in Hajiganj the filter media life exhausted at 28% of the claim. The technology was found suitable for deployment in regions where water matrix meet the conditions of iron ≤10 ppm, phosphate ≤.0 ppm and pH ≤7.5. The BCSIR recommended that the technology should be deployed in wells of similar type of water matrix. Among other things, the BCSIR stated that post–deployment performance monitoring of the technology is a necessary condition for its deployment. Hajiganj was identified as a region not suitable for READ–F deployment. The BCSIR stated that the proponent should train at least one user of each unit on installation, operation and maintenance (BCSIR 2003).

Plate 1 READ-F Household Arsenic Removal Unit (2008)

Plate 2 READ-F Household Arsenic Removal Unit (2012)

Plate 3 READ-F Community Based Arsenic Removal Unit in Shahrasti (2008)

Plate 4 READ-F Community Based Arsenic Removal Unit in Shahrasti (2012)


ইহা আমাদের সম্পদ
আসুন সকলে মিলে
এর যত্ন নিই।
READ-F
সমাজ ভিত্তিক আর্সেনিক দূরীকরণ ইউনিট।
টিউবওয়েল চেপে পানি নিন।

Plate 5 Arsenicosis Awareness Billboard (2008)

Plate 6 Private Arsenic Removal Unit (2012)

Appendix C Laboratory Results

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Ref. No. : BACERDU\2408\2003\10\29
Date : 27/12/2010

To

Osiel GONZALEZ DAVILA

Dear Sir,

Please find enclosed herewith the analytical results of the supplied water sample.

Thanking you for your trust on us.

Analytical results of the supplied sample

Sample No.	Parameter	Results (ppm)
01 DTW SH	Arsenic (As)	Below Detection Limit (BDL)
02 HTW SH b	Arsenic (As)	0.030
03 HTW Sha	Arsenic (As)	BDL
04 UNIDO HARU	Arsenic (As)	BDL
05 BULD FILT	Arsenic (As)	0.224
06 BULD HTWI	Arsenic (As)	0.337
07 BULD DHTWZ	Arsenic (As)	0.294
08 BULD CBARU	Arsenic (As)	0.506
09 DEHALA HTW	Arsenic (As)	0.402
10 DEHALA CBARU	Arsenic (As)	0.100

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Appendix D Letter UNIDO

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RE: Arsenic contamination in Community Based Arsenic Removal Units.

Dear Sir/Madam,

I am contacting you in relation to the UNIDO Project No. TF/BGD/03/001 "Improving Human Security by Mitigating Arsenic Poisoning in Bangladesh." During December 2010 as part of my PhD research I visited the UNIDO Area Office in Shahrasti, Chandpur. I was informed that the UNIDO project installed nine Community Based Arsenic Removal Units (CBARU's) in the area. My research has brought to light several potentially alarming problems with the CBARU's, and we feel duty bound to inform you of them.

Firstly, when tested for arsenic at the Bangladesh – Australia Centre for Environmental Research of the Department of Soil, Water and Environment at the University of Dhaka, water samples taken from the CBARUs in the villages of Boldigi and Dehala were found to contain concentrations **far above** the Bangladeshi guideline value for Arsenic content in water (0.05 mg/L). Please see the results attached.

Secondly, those CBARU's also present mechanical problems and the villagers are not able to collect water from them. The CBARU's located in the villages of Khonossore, Podua and Icapura also show mechanical problems (some pieces were damaged and I was informed that they are not available in the local stores) and it was impossible to collect water samples for its analysis. Furthermore, the villagers informed that in all cases the CBARU has not been working for at least 6 months and they are forced to collect water from other sources (mainly hand tube-wells that in most cases present toxic Arsenic levels).

This is clearly a potentially important health issue, particularly as villagers are using water from the CBARUs under the impression that they provide uncontaminated water. Interestingly, from face to face surveys to the villagers I found that almost 70% of the interviewees (from a sample of 182) used the CBARU regularly when it was working and 98% think that it is worth collecting their drinking water from the CBARU.

We understand that there is a potential problem with our sampling (we have only taken one sample from each CBARU) but we think that the concentrations of arsenic found there merit further investigation with a view to remedying the situation. In addition, while we are not entirely sure with whom responsibility lies for maintenance, the issue of maintenance and the provision of spare parts seems to be something that could be easily remedied.

We would be happy to talk further with you in this regard. If you require further information do not hesitate contacting either one of us. Given the well known health cost of arsenic contamination our feeling was that these initial results ought to be shared with the appropriate authorities.

Kind regards

Dr Ben Groom and Osiel González Dávila

25/2/11

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Appendix D Survey questions

Folio:

Health and Groundwater Arsenic Contamination
PhD in Economics Project
Economics Department University of London - SOAS

Researcher: Osiel González Dávila
Enumerator:

	Day	Month	Year
1. Date			2012

Zila	Chandpur		Upazila	Shahrasti

2. Village	

3. For how long have you been living in Shahrasti?	

4. Gender	Female	Male

5. Age (years)	

5. Marital Status	Single	Married	Divorced	Widow	Widower	Spouse Disappeared

6. Number of Household Members	
7. Number of children in the household	

8. Education (C or I)	No education	Primary school	SSC secondary school	HSC Higher Secondary Certificate	Graduate Education	Post Graduate

9. Housing	Pacca	Semi Pacca	All Tin	Kutcha	Jhupri	Others

10. Main Source of income									
Agriculture	Fishery	Commerce	Transport	Services	Government employee	Teacher	Doctor	Advocate	Others

11. Household Monthly Income (Tk)	12. Monthly expenditure in food	13. Do you produce your own food?

14. What is your main drinking water source?	Hand tube well	Deep tube well	Pond	Other:

15. How many times is water collected for the household per day?	

16. Is your drinking water supply arsenic contaminated?	Yes	No	Do not know

17. Do you drink hand tube well water?	Yes/No

18. If yes, what is the reason?	

19. Do you use a filter for your water?	

20. What kind of filter?	

21. Do you use a CBARU? How many times per month?	

22. If not daily, could you please tell me the reason?	

23. Is the CBARU far from home?	Yes/No

24. Minutes walking	

25. Would you go more often if it was closer?	Yes/No

26. State Minutes walking	

27. Do you know about the Arsenic disease (arsenicosis)?	Yes	No
28. Do you know the symptoms of arsenicosis?	Yes	No

29. Do you think your source of drinking water will provoke you arsenicosis?	Yes	No

30. Are there arsenicosis patients in your family?	
Yes	No

31. Sex	32. Number	33. Sex	34. Number
Female		Male	

35. Do you take the patient to the doctor?	Yes	No

36. Doctor fee	
37. Transport cost	
38. Medicines costs	

Chapter 3

Assessing the Adoption of Arsenic Removal Technologies in Rural Bangladesh: an Experimental Approach

By Osiel González Dávila
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Abstract

In this chapter, experimental data from rural communities in Bangladesh are used to assess the adoption of groundwater arsenic removal technologies in relation to risk and time preferences. The identification of such preferences is important because they determine people's propensity to use arsenic removal technologies and their ability to avoid arsenic related illnesses. Thus, changes therein foster or hinder health outcomes. The results show that education and gender are important explanatory variables. Further, the use of arsenic removal technologies is explained by the respondents' time preferences. Those with time inconsistent preferences are less likely to use filters. The results are very important since 40% of the respondents showed preference reversals. Therefore, they are more likely to procrastinate in the use of filters increasing the likelihood of adverse consequences on their health.

Keywords: Groundwater arsenic contamination, preferences, field experiments, Bangladesh.

Introduction

This chapter discusses the implications for technology adoption of risk preferences and time inconsistent preferences. The scarce use of arsenic removal technologies despite having them available in the household or neighbourhood and the awareness of the risk of arsenicosis lead to the hypothesis that people in the affected areas exhibit time inconsistent preferences when making the intertemporal choice of using or not arsenic removal technologies. We must remember that skin lesions have a latency period between 5 to 20 years from first exposure to visible sypmtoms. This long latency period may distort individuals' perception of the problem. Inter-temporal choices involve *immediate costs* -where the costs of an action are immediate but any rewards are delayed -or *immediate rewards*- where the benefits of an action are immediate but any costs are delayed. Time and risk preferences play an important role in the use of arsenic removal technologies. In terms of time preferences, it can be expected that a person with time inconsistent preferences will procrastinate in completing an unpleasant task (i.e. filtering water). On the other hand, it can be expected that risk-averse individuals are more likely to use arsenic removal technologies. Thus, the aim of this chapter is to examine the causal effect of economic behaviour on exposure to arsenic using experiments in which payoffs vary between choices across two dimensions: time and risk.

The rest of the document is organised in the following way: section one presents a review of the main theoretical developments related to inter-temporal decision making. A brief literature review of the applications of the theoretical framework developed in section one to different problems related to self-control is presented in section two. The adoption of arsenic removal technologies and its relation with time and risk preferences is discussed in section three. Section four explains the survey and experimental design used. Sections five presents the experimental games conducted during fieldwork. The last section offers policy recommendations and concludes.

1. Intertemporal decision making

Intertemporal choices are decisions that involve comparing consequences that occur at different points in time. Intertemporal decision making has been analysed using Discounted Utility (DU) models. A DU model was initially developed by Samuelson (1937) when he analysed the measurement of the marginal utility of income to an individual whose tastes maintain a certain invariance throughout time. One of the main assumptions in Samuelson's model is that the rate of discount of future utilities is a constant. Thus costs and benefits occurring at different times can be made comparable by discounting future utility by this constant factor. Therefore, this implies that there is no time preference of any kind or a premium on future utilities. Assuming that the utility of a choice is equal to the sum of its utility in each time period, the DU model allows to calculate the overall utility of an option whose consequences are intertemporal simply by multiplying each utility by a discount factor. The utility of option x, U(x), can be calculated as follows:

$$U(x) = \sum_{t=0}^{\infty} \delta^t U(x_t) \qquad (1)$$

where x_t is the consequence of option x in period t, and δ is the constant discount factor, such that

$$\delta = \frac{1}{1+d} \qquad (2)$$

where d is referred to as the discount rate. As equation (2) shows, larger discount rates (d) are associated with smaller discount factors (δ) – that is, a decision maker whose discount rate is twenty percent will care less about the future than a decision maker with a discount rate of only ten percent. Thus, decision makers with large discount rates are more impatient than decision makers with small discount rates (Goldin 2007). Following Samuelson, O'Donoghue and Rabin (1999a), explain that patience can be captured by assuming that people discount streams of utility over time exponentially. In other words, an individual's relative preference for wellbeing at an earlier date over a later date is the same no matter when she is asked. They call such preferences time–consistent. However, there is evidence in the literature that individuals like to experience rewards soon and to delay costs until later. And when considering trade–offs between two future moments, present biased preferences give stronger relative weight to the earlier. This phenomenon is explained by Laibson (1997:445) who states: "hyperbolic discount functions are characterized by a relatively high discount rate over short horizons and a relatively low discount rate over long horizons. This discount structure incites a conflict between today's preferences, and the preferences that will be held in the future." In the animal psychology literature, authors like Chung and Herrnstein (1967) used $1/\tau$ hyperbolic discount functions. A function like $1/(1 + \alpha\tau)$, with $\alpha > 0$ was used by Ainslie (1992) . In their paper, Loewenstein and Prelec (1992) proposed a general hyperbolic discount function that weights events τ periods away with factor $1/(1 + \alpha\tau)^{-\beta/\alpha}$,with α, β> 0. The α coefficient determines how much the function departs from constant discounting. In the limit, when α goes to zero, the exponential discount function is $\theta = e^{-\beta t}$. Laibson (1997) adopts a discrete-time discount function: $\{1, \beta\delta, \beta\delta^2, \beta\delta^3, \dots\}$. This "quasi–hyperbolic function" reflects the sharp short-run drop in valuation measured in the experimental time preference data and has been adopted as a research tool because of its analytical tractability. In the literature, "hyperbolic discounting" has been employed to refer to any declining discount rate, not just discount functions that follow a hyperbola. Hyperbolic and quasi–hyperbolic discounting imply a time varying discount rate, and therefore, they can result in time inconsistent preferences (Groom *et al* 2005:473).

2. Eliciting Risk Preferences

The expected utility theory (EUT) provides a standard approach to elicit risk preferences. In the EUT framework, a decision maker chooses between risky or uncertain prospects by comparing expected utility values (Mongin 1997). Assuming that a decision maker has a constant relative risk aversion (CRRA) the utility function defined over the rewards she makes choices over is:

$$U(M_t) = \frac{EM_t^{1-\theta}}{1-\theta} \qquad (3)$$

where $U(M_t)$ is the utility of a monetary outcome M_t at time t and θ measures the degree of relative risk aversion that is implicit in the utility function. E is an expectations operator. If $\theta = 1$, then the function is defined as $U(M_t) = Eln(M_t)$, for $\theta = 0$ the agent is risk-neutral, for $\theta > 0$ the agent is risk-averse, and for $\theta < 0$ the agent is risk-seeking. Assuming exponential discounting and considering two certain monetary outcomes (M) at time t and at time t+k, an agent is indifferent between these two outcomes if the following equation holds:

$$U(M_t) = D(k)U(M_{t+k})$$

where $D(k) = \frac{1}{(1+d)^k}$ (4)

$U(M_t)$ is the utility of monetary outcome M_t at time t as specified in equation (3), k is the horizon for late delivery of monetary outcome M_{t+k} and D(k) is the discount function. If agents are risk-neutral, equation (4) can be written as:

$$M_t = \frac{1}{(1+d)^k} M_{t+k} \qquad (5)$$

If agents value two monetary outcomes M_t and M_{t+k} equally in spite of their timing difference, then the implicit value of θ for which equation (5) holds as equality can be derived (Lammers and Van Wijnbergen 2008). It should be mentioned that this model constitutes the theoretical background for the field experiments described in the following sections.

3. Applications in the literature

This approach has been used in different studies related to self-control like alcohol consumption or condom use as well as in technology adoption. For example, Lammers and Van Wijnbergen (2008) using experimental data collected from students in South Africa analyse the relation between perceived health status and time and risk preferences. Their results show that HIV positive respondents and participants that perceive to have a high HIV contraction risk are less risk-averse. Their results suggest that their respondents do not practice unsafe sex because of ignorance, but because they are less risk-averse and value the future less than those that do not. Aronsson and Thunström (2008) analysed the case of a "government intervention in an economy where a self–control problem caused by quasi–hyperbolic discounting may lead to excessive consumption of unhealthy food." In their research, Vuchinich and Simpson (1998) conducted two studies in order to understand alcohol consumption and time preferences. They found greater temporal discounting among heavy social drinkers and problem drinkers. Both studies found that a hyperbolic function described temporal discounting more accurately than an exponential function. In relation to technology adoption, Duflo, Kremer and Robinson (2009) analysed the use of fertilizer in Western Kenya. They developed a model in which some farmers have time inconsistent preferences and are partially naïve. In their model, they also consider a small fixed cost of purchasing fertilizer. This setting provokes farmers' procrastination in their fertilizer purchases until the profits from their harvest are spent. Thus, they conclude that reductions at harvest time of fertilizer prices could lead to increases in fertilizer use among time-inconsistent farmers, reducing the costs of heavy state subsidies.

One problem that is parallel to the adoption of arsenic removal technologies is the adoption of insecticide-treated bed nets (ITNs) in malaria prone areas. Tarozzi *et al* (2009) explain that in the majority of the affected areas the use of ITNs remains very low and public health interventions often have insufficient resources to provide complete ITN coverage for all the people at risk. The most frequent explanation for low usage is cost but other possible factors include the information quality about potential benefits and the inability to save money for investing in bed nets. In the literature, it is claimed that commitment devices can help poor households to overcome time-inconsistency in their preferences (see for example Ashraf, Karlan and Yin, 2006 or Duflo, Kremer and Robinson, 2009). O'Donoghue and Rabin (1999b), state that a person who is time inconsistent and unaware of the time inconsistency will procrastinate in completing an unpleasant task (for example filtering the water). Therefore they suggest the design of temporal incentive schemes, which reward agents based on when they complete their task. Laibson (1997:445) states that "all illiquid assets provide a form of commitment and all the illiquid assets have the same property as the goose that laid golden eggs. The asset promises to generate substantial benefits in the long run, but these benefits are difficult, if not impossible, to realize immediately." In this sense, Ambec and Treich (2007) propose a model in which people with limited self-control can sign binding financial agreements among themselves forming coalitions. The financial agreements may help them to alleviate their self-control problems. However, it should be noted that there is evidence that commitment mechanisms may not always improve technology adoption. Using an experimental approach, Duplas (2009) analysed the adoption of long lasting insecticide-treated bed nets in Kenyan rural households. The effects on adoption were tested through two interventions: contrasting the framing of the perceived benefits and having people verbally commit to purchase the product. Her results show that none of these interventions had a statistically significant effect on the household's investment in bed nets. The gender of the household member targeted was also irrelevant. Nevertheless, the take-up is price of the technology is sensitive and correlated with indicators of household's wealth.

4. Adoption of arsenic removal technologies and time and risk preferences

Safe drinking-water is a basic need for human health and well-being. In the literature on water risk management chemical contaminants in drinking water are usually given a lower priority than microbial contaminants. The reason is that negative health effects from chemical contaminants largely occur after long-term exposure. In contrast, the effects of microbial contaminants are usually immediate (Thompson et al 2007). However, a growing body of research has concluded that arsenic contamination of groundwater in Bangladesh is a very serious threat to the health and well-being of mostly rural households whose main source of drinking water is contaminated (see for example Smith et al 2000, Johnston and Sarker 2007, Cherry et al 2008, Argos et al 2010, Chen et al 2013, Rahman et al 2015, etc.). In this context, the use of arsenic filters is essential. It is acknowledged that competing and background risks can influence households filter use decisions. For example, seasonal flooding can hinder the access to arsenic-free water sources by increasing the time needed to reach arsenic-free water wells. Nevertheless, although livelihoods in Bangladesh are often fragile and full of risks, the health and well-being risks posed by microbial and chemical water contamination is a top priority for households. Interviewees are well aware of the health risks posed by arsenic contaminated water as explained in the previous chapter. The scarce use of arsenic removal technologies despite having them available in the household or neighbourhood and the awareness of the risk of arsenicosis lead to the hypothesis that people in the affected areas could have a very high discount rate or they could be using a declining discount rate in making the intertemporal choice of using or not the arsenic removal technologies. As previously mentioned, skin lesions provoked by the consumption of arsenic contaminated groundwater have between 5 to 20 years of latency from first exposure to visible sypmtoms. This long latency period may distort individuals' perception of the problem. In our case, the hypothesis is that some people in the affected areas would procrastinate in the use of ARUs. The aim of this chapter is to examine the causal effect of economic behaviour on exposure to arsenic using experiments in which payoffs vary between choices across two dimensions: timing and riskiness. Therefore, two research questions were posed: a) what are the most important explanatory variables that determine the decision of using or not arsenic removal technologies? b) do people aware of the consequences of consuming arsenic contaminated water have a higher propensity to invest in the future, and are they less susceptible to taking risks? A structural questionnaire for quantitative analysis is used in order to answer these important questions. First, detailed information on the knowledge of arsenic relevant information (symptoms knowledge, ownership of arsenic removal technologies, etc.) and on a range of other household and community variables was collected. Then, a series of field experiments were conducted in order to understand risk and time preferences.

5. Structural questionnaire for quantitative analysis and implementation

A set of primary socio-economic data and information about perceptions and attitudes towards arsenic contaminated groundwater was obtained through a pre–tested standardized structural questionnaire for quantitative analysis (see Appendix 1). The survey is divided into six sections. The first section records the time and place of the interview and the number of years that the respondent has lived in the village. The second section records respondents' gender and age. Social information like the marital status of the respondent, the number of household members and the number of children 14 years old and younger was captured in section three. Six variables were selected for registering economic information in section four. Monetary and non-monetary factors that impact the household income were considered. First, the level of education of the respondent was asked. The second question is about the type of housing available. The respondent's main economic activity was also asked. The four monetary variables included are: The household income, the household monthly expenditure in food and production for self-consumption. All the monetary variables are expressed in Bangladeshi Takas. Section five gathers information about water supply features. Three options were considered to differentiate the water supply sources: hand tube-well, deep tube-well, pond and other. It was also asked how many times is the water collected per day. The next questions are very important for the research. It was asked if the respondent drinks arsenic contaminated water and after that if they drink hand tube-well water (almost all the hand tube-wells in the region are contaminated with arsenic). If yes, it was asked what was the reason. Next, it was asked if the household uses a filter for their water consumption and what type of filter. Next, it was asked if the household uses a Community Based Arsenic Removal Unit (CBARU), the reasons for using it and the distance to the household. Finally, section 6 records information about the knowledge of arsenicosis and if the respondent has affected relatives by arsenicosis. After the socio-economic survey was concluded, the experiments detailed in the following sections to elicit time and risk preferences were conducted and the results recorded at the end of the instrument. A random and stratified sample of 300 households in 6 villages of Shahrasti, Chandpur was used. These households were drawn from the set of villages visited in 2010 to collect data on adoption of arsenic removal technologies. The 6 villages were revisited in 2012 and 300 respondents were invited to participate in a series of experiments. Arsenic removal technologies (CBARU, HARU and deep tube wells) are available in such villages. According to the Bangladesh Centre for Advanced Studies (BCAS 1999), in Shahrasti 99% of the tube wells are arsenic contaminated. Thus, exposure to arsenic is random: the likelihood of an individual being exposed to arsenic is independent of variables such as income, level of education, etc. In other words, arsenic exposure is not systematically related to individual characteristics. Nevertheless, it is considered that systematic differences in the adoption of arsenic removal technologies between villagers can be attributed to different levels of exposure to information about arsenic and its effects and to risk and time preferences. It is assumed that our 300 participants are drawn from the same distribution of preferences in the Bangladeshi population. Three MSc students at the University of Dhaka were hired as research assistants. Following the training of the research assistants, a wide pilot survey was conducted in April 2012 to ensure that the participants were able to understand the experiments without much effort. The survey was modified in May and the final experiments were conducted in June 2012. Because of the nature of the questionnaires only individuals 18 years old or above were interviewed, preferably the head of household or a mature respondent if the head of household was not available. Table 1 shows the average profile of sampled households.

Table 1 Average profile of sampled households

Description	Mean	SD
Age of the respondent (in years)	36.73	13.41
Percentage of female respondents	52.72	50.01
Education of the respondent (no. of schooling years)	3.41	3.31

Number of household members	6.20	2.49
Number of children (under 14) in the household	1.95	1.27
Marital status (percentage married)	86.05	34.70
Monthly household income (BDT)	13,156	10,049
Monthly expenditure in food (BDT)	8,215	5,619
Monthly expenditure in medicines (BDT)	3,705	12,571

Only individuals 18 years old or above were interviewed. The respondents' average age is 37 years. This average is consistent with the survey design because normally mature people are responsible for the household administration. According to the 2011 Population and Housing Census (BBS 2012:10), the female population in Chandpur is 1,270,187 people (52% of the total) and the male population 1,145,831 people (48% of the total). In relation to the respondents' gender the survey is representative of the population's ratio. The percentage of female and male respondents in the survey is 52% and 48% respectively. On average the respondents have 3.4 years of schooling. The average number of household members is 6.20 and on average there are two children under 14 in each household. In relation to the marital status of the respondents, we can appreciate that almost 86 per cent are married. This is consistent with the average age found in the sample. The average household income is BDT 13,156. The average monthly expenditure in food is BDT 8,215. This means that approximately 62% of the household income is used in buying food. The average monthly expenditure in medicines in households where there are arsenicosis patients is BDT 3,705.

6. Experimental games

Once the socio-economic information was collected, the enumerators proceeded to the collection of experimental information. In this section of the interview, adapted versions of well-established experimental game protocols were used. A time preference experiment and a risk experiment were implemented in this order. Since many of the interviewees had received little or no education (see table 1), the research assistants used clear and visual instructions to make it easier for illiterate respondents to understand the consequences of the decisions they made in the game protocols (see Appendices A, B and C).

6.1 Time preference experiments

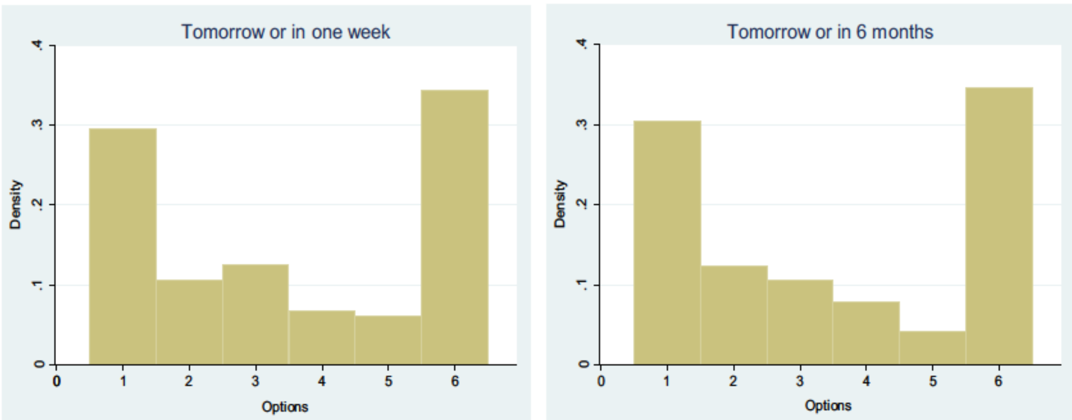
The enumerators first conducted two experiments (the visual materials used in the experiment are available in appendices B and C), which asked the respondents to consider payoffs with the same rate of return, only over different time horizons: a) tomorrow or in one week and b) tomorrow or in six months. The objective was to identify the discount rate and preference reversals among the interviewees. This information is relevant because it was hypothesised that individuals with high discount rates or with preferences reversals may not use their filters. The time preference experiments are an adaptation of the protocol devised by Holt and Laury (2002). The theoretical bases of this experiment are explained in section 2 and rely on the utility maximization model explained there. The model assumes exponential discounting and considers two monetary outcomes at time t and at time t+k. The respondents' stated preferences in the experiment in two points of time in the future allow the estimation of their utility discount rates. Therefore, the participants were asked to choose between BDT 50 one day later and a larger amount one week later increasing from BDT 52 to BDT 150. They were asked to make this choice six times. In the second experiment it was asked to the participants to choose between BDT 50 one day later and a larger amount six months later. This time the amount to be received later increased from BDT 55 to BDT 1,400 (see Table 2). Increasing the interest rate *d* over the six decisions allows to observe the point at which a subject switches from preferring BDT 50 tomorrow to preferring 50 (1 + *d*) BDT in one week and between BDT 55 one day later or 50 (1 + *d*) six months later. The switching point allows measuring the interviewee's discount rate; the earlier people switch the more patient they are.

Table 2 Structure of the time experiment

A) Short Term Experiment			B) Long Term Experiment		
Choice	Today	In one week	Choice	Today	In Six Months
1	50	52	1	50	55
2	50	55	2	50	124
3	50	60	3	50	240
4	50	70	4	50	430
5	50	100	5	50	900
6	50	150	6	50	1400

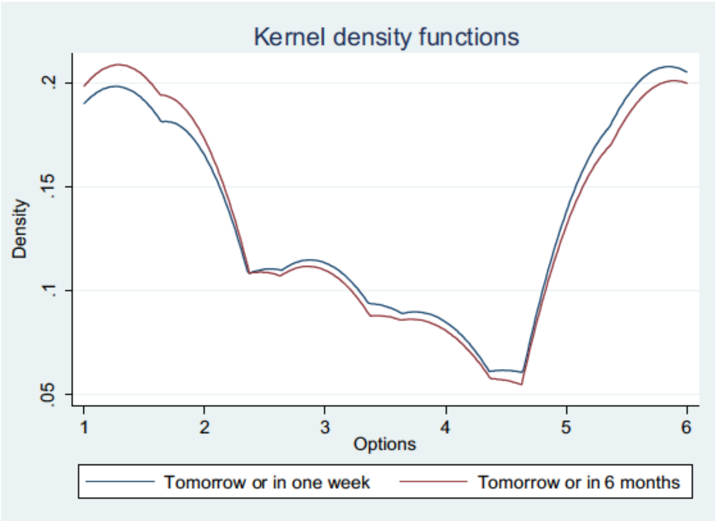
Figure 1 shows the participants' time preference choices, as illustrated by their switch points to the larger amount to be received at the later time. In both experiments, participants choosing option 1 are the most patient in the sample. 29.6% of the respondents chose this option and 30.5% in the second experiment. In contrast, participants choosing option 6 are the most impatient. In the first experiment 34.4% of the interviewees chose this option and 34.6% in the second experiment chose this option in.

Figure 1 Time preferences



A couple of kernel density functions are used to illustrate graphically the fact that a number of respondents showed preference reversals. Kernel density estimates are closely related to histograms. However, they could be endowed with properties such as smoothness or continuity by using a suitable kernel density estimator. The smoothness of the graphic is desired because the changes in the time preferences are easily identified. Figure 2 shows the kernel density functions for the two experiments. It should be noted that the light coloured line is above the dark coloured line in options 1 and 2 and below the dark coloured line in options 3, 4, 5 and 6. In this graphic it is clear that a number of people switched to options 1 and 2 meaning that they are more patient in the long term. This is evidence of preference reversals.

Figure 2 Time preferences kernel density functions



In order to conduct a more refined analysis, it is necessary to identify the type of discount that the interviewees use. This could be illustrated by comparing the answers in both experiments. If there are no preference reversals then the respondent has time consistent preferences. Figure 3 shows the respondent's time preferences densities. It is important to note that 60% of the respondents have time–consistent preferences. Their discount of utility streams over time exponentially. Meaning that their relative preference for wellbeing at an earlier date over a later date is the same no matter when they are asked. On the other hand, it should be highlighted that 40% of the respondents show preferences reversals. These results have important policy implications as we will see in the last section.

Figure 3 Respondent's time preferences densities

6.2 Risk preferences experiment

The second experiment was the risk preferences experiment. Here a game based on Eckel and Grossman (2002 and 2007) was used. Participants were presented with a 6 choice lottery. Each lottery has a low and high amount. To determine payment, the participant played the gamble chosen by tossing a coin. Appendix D presents the gambles in the choice set. All the gambles involve a 0.5 probability of a low or high payoff. The range of gambles includes a safe alternative involving a sure payoff with zero variance. The gambles decrease in both expected return and risk moving from Gamble 1 to 5 (see table Table 2).

Table 3 Structure of the risk experiment

Choice	Payoff		Expected Payoff	Risk [a]	Risk Classification [b]
	Heads	*Tails*			
1	0	75	37.5	37.5	Neutral to preferring
2	5	70	37.5	32.5	Slight to neutral
3	15	60	37.5	22.5	Moderate
4	20	50	35	15	Intermediate
5	25	40	32.5	7.5	Severe
6	30	30	30	0	Extreme

[a]Measured as the standard deviation of the expected payoff

[b]According to Binswanger (1980) classification

More risk-averse subjects would choose lower-risk, lower-return gambles; risk-neutral subjects would choose gamble 1 or 2, which have the highest rate of return; risk-seeking subjects would choose gamble 1. This experiment was designed to be as simple as possible, while retaining a reasonable range of risky choices, and takes only a few minutes to explain and implement. Figure 4 shows a histogram with the risk preferences. We can observe that almost half of the respondents chose option 6, meaning that they are risk averse. And more than a quarter of the respondents chose option 1. From the Kaplan Meyer (see figure 5), it appears that female respondents are more risk averse than male respondents. The red survival function is higher for females between choices 2 and 6. This indicates that they are willing to swap to the heads payoff at lower probabilities of the higher payout in the tails option. In figure 6, we can see that people with higher levels of education are more risk averse. The proportion of people opting for the risky option smoothly declines as we head towards choice 6. Figure 7 shows risk preferences by age groups. People between 30 and 39 years are the most risk averse. Younger people (in the 18-29 age group) appear to be risk lovers. Figure 8 shows risk preferences by marital status. It appears that single respondents are risk lovers.

Figure 4 Risk preferences

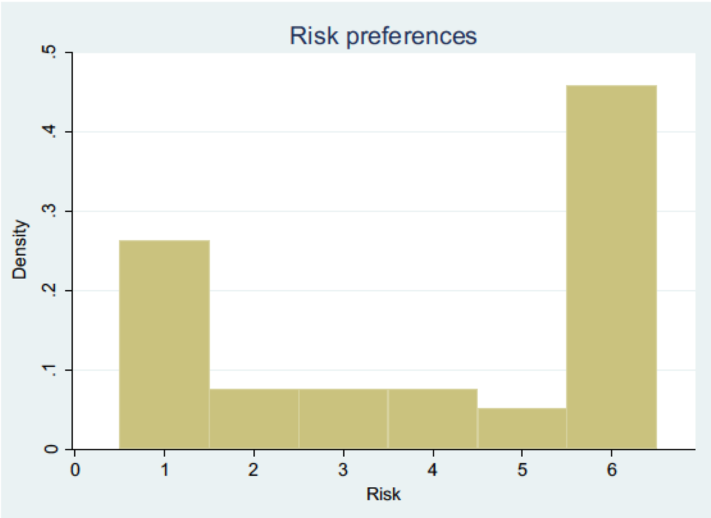


Figure 5 Risk preferences by gender [run the test]

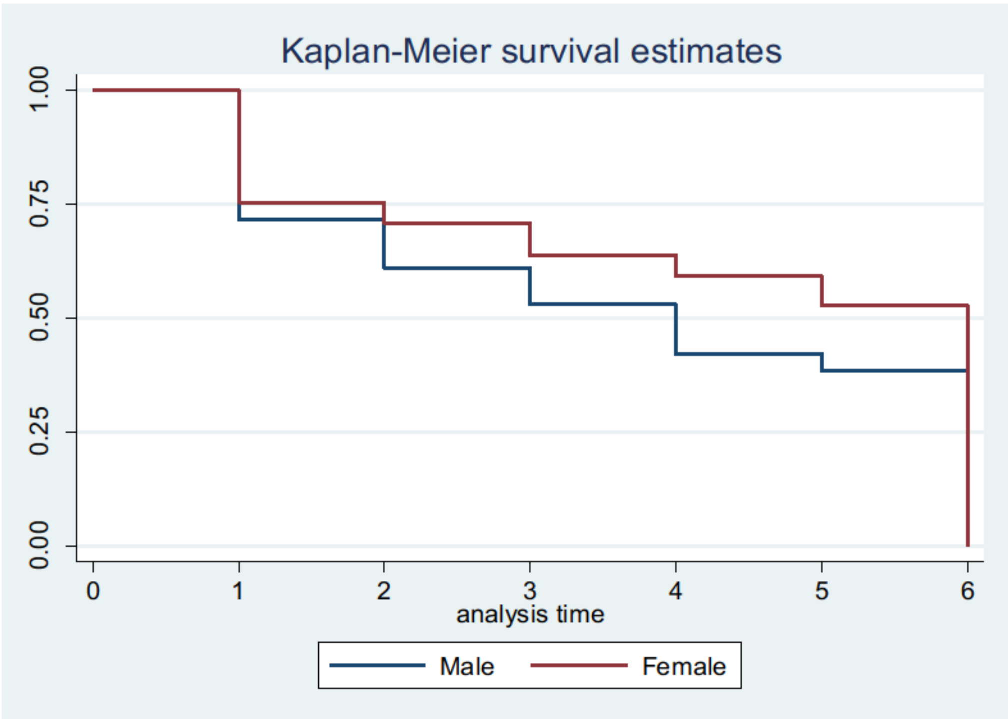


Figure 6 Risk preferences by education

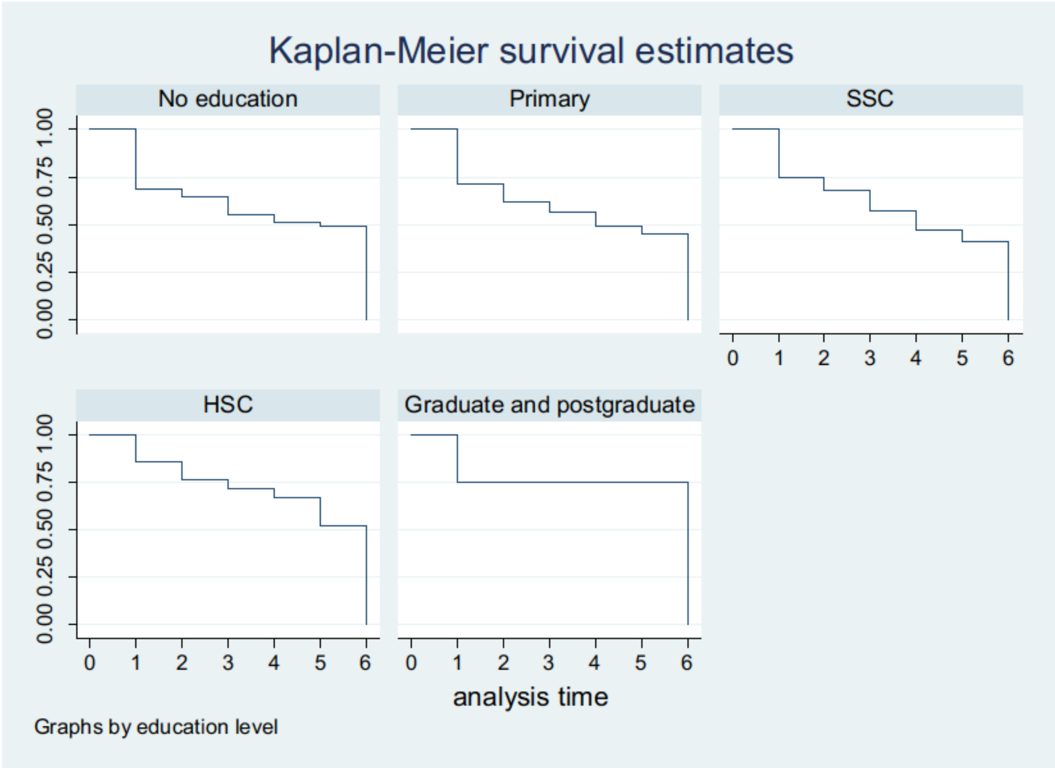


Figure 7 Risk preferences by age groups

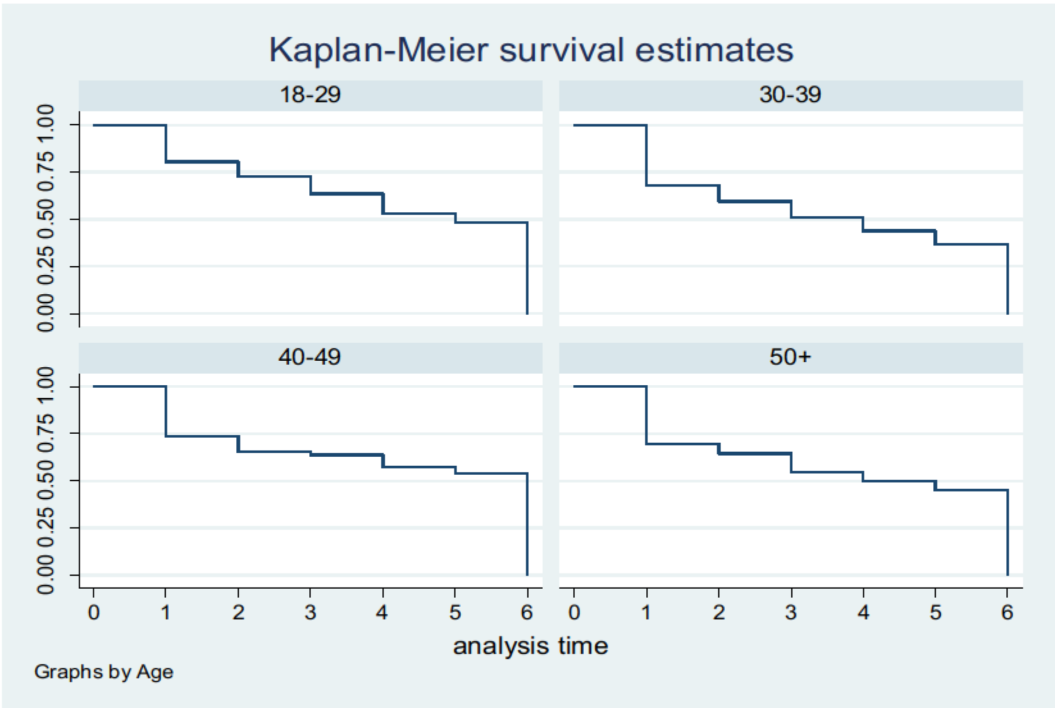
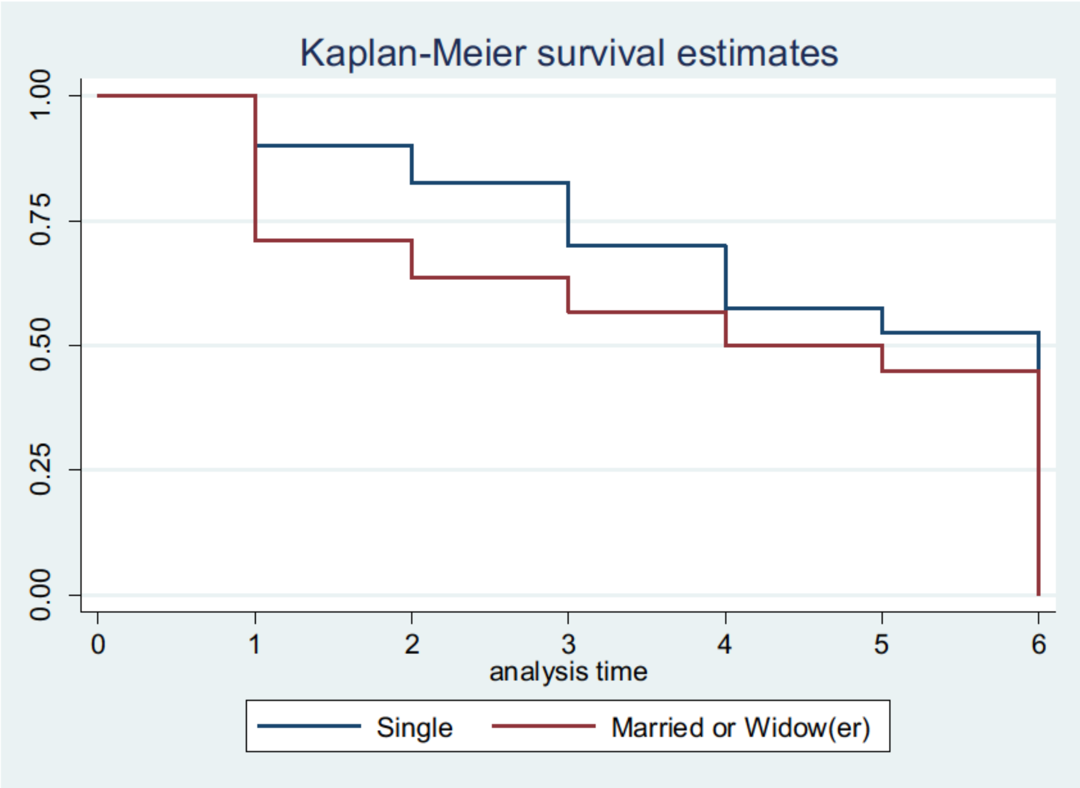


Figure 8 Risk preferences by marital status



6.3 Filter use

It is very important to understand what determines the use of the filters in the household. Table 2 shows the definitions of the variables used in the econometric analysis that is conducted in this section. In table 2 it is established that the use of filters for drinking water is a dummy variable (where 1=Yes and 0=No). The variables taken into consideration to analyse the use of filter are the respondent's gender, the respondent's age (older respondents are expected to use their filters), number of children under 14 in the household (more children in the household could imply less time to filter the water an less disposable income to buy a filter), the respondent's knowledge of arsenicosis symptoms, the food expenditure per capita as percentage of total income per capita, the village and the experiments results. Three probit regression models were estimated using the variables contained in Table 2. The response variable is Filter and takes the value of 1 if the household used a filter and 0 otherwise. The considered explanatory variables are Gender (dummy variable that takes the value of 1 if the respondent is Female and 0 otherwise. The Age of the respondent in years is included (it may be that younger or older respondents use more the filters). The number of Children under 14 in the household could affect the use of the filter by the head of the household if there is evidence of altruism. The level of education of the head of the household in years is included and an income proxy variable. It is expected that wealthier and more educated respondents will use more their filters. Also Households who have arsenicosis patients are expected to use more their filters as well as if the y know the symptoms. Risk averse respondents are expected to use more the filters as well as time consistent respondents. Respondents with high discount rates in the short and long term (one week and 6 months discount rate) may use less their filters.

Table 2 Variables definition and expected signs

Variable	Definition	Expected Sign
Filter	Use of filter for drinking water (1=Yes, 0=No)	
Gen	Respondents gender (1=Female, 0=Male)	Ambiguous
Age	Age of respondent (in years)	Ambiguous
Children	Number of children under 14 in the household	Positive if there is altruistic behaviour
Edu	Respondents education (in years)	Positive
KnowSympt	Respondent knows Arsenicosis symptoms (1=Yes, 0=No)	Positive
Patients	Has arsenicosis patients in her family (1=Yes, 0=No)	Positive
LnFoodInc	Natural log of food expenditure per capita as percentage of total income per capita	Positive
Risk	Experiment results of risk preferences	Positive if risk averse
TimePref	Time preferences (1=Time inconsistent, 0=Time consistent)	Positive if time consistent
Timeshort	Experiment results of time preferences game in the short term	Depending on the discount rate
Timelong	Experiment results of time preferences game in the short term	Depending on the discount rate

Table 3 shows the designed probit regression models. The first model excludes the discount rate in the long and the short term. Each rate is included in models 2 and 3. In all three models gender is a significant variable. The positive sign means that women are more likely to use filters for drinking water than men. The variables age and children have the expected sign but they are not statistically significant. A second explanatory variable is education. More educated respondents are more likely to use a filter. In relation to the geographical variables, people living in Khonosore, Isapura and Chototula are less likely to use filters. It should be highlighted that the use of filters is also explained by the respondents' time preferences. The negative sign means that respondents with time inconsistent preferences are less likely to use filters. These results are very important. In section 5.1 it was discussed that 40% of the respondents showed preference reversals. This means that those individuals are more likely to procrastinate in the use of filters and thus are more likely to get arsenic related diseases. Also interesting is that the time inconsistency effect is stronger than the level effect. Risk aversion is not important, this could reflect the difficulty of the respondents to relate risk with filter use and implies that another more appropriate instrument to capture risk preferences is required. Therefore, this result requires further research. Here again we find evidence that the impact of information is not important: if they know the symptoms this is not important compared to the time preference effect.

Table 4. Estimated Probit regression models of filter use (Dep. Var.=Filter)

Variable	m1	m2	m3
Gen	0.55*	0.55*	0.54*
Age	0.01	0.01	0.01
Children	-0.02	-0.04	-0.04
KnowSympt	0.77	0.74	0.77
Edu	0.41***	0.43***	0.43***
LnFoodInc	-0.05	-0.02	-0.03
Khnosore	-1.40***	-1.38***	-1.40***
Isapura	-1.19**	-1.09**	-1.11**
voldigi	-0.71	-0.59	-0.56
Chototula	-0.49	-0.46	-0.50*
Risk	0.05	0.04	0.04
TimePref	-0.61**	-0.54*	-0.53*
Timeshort		0.07	
Timelong			0.09
_cons	-2.74*	-3.16*	-3.20*
N	268	268	268
r2_p	0.23	0.24	0.24
ll	-58.6	-57.9	-57.6
chi2	34.94	36.34	36.94

legend: * p<.1; ** p<.05; *** p<.01

Table 5 shows the marginal effects for filter use using model 1. It should be noted that if the respondent is a female the likelihood of using a filter increases in 4.4%. An increase in one year of education increases in 3.3% the likelihood of using a filter. If the respondent knows the arsenicosis symptoms the likelihood of using the filter increases in 4.1%. The regional effects indicate that if the respondents live in Khonosore, they are 6.5% less likely to use the filter. In contrast, if the respondents live in Isapura, they are 5.2% less likely to use the filter. Finally, the likelihood of using a filter increases in 4.6% if the respondent is time consistent.

Table 5. Marginal effects

Probit regression, reporting marginal effects

Variable	dF/dx	Std. Err.	z	P>|z|	x-bar	[95% C.I.	]
Gen*	0.044	0.025	1.790	0.074	0.522	-0.005	0.094
Age	0.001	0.001	1.130	0.258	36.470	-0.001	0.003
Children	-0.001	0.008	-0.160	0.871	1.948	-0.018	0.015
KnowSympt*	0.041	0.020	1.390	0.165	0.836	0.002	0.079
Edu	0.033	0.013	2.920	0.003	1.500	0.007	0.059
LnFoodInc	-0.004	0.024	-0.180	0.859	4.159	-0.052	0.043
Khnosore*	-0.067	0.022	-2.730	0.006	0.220	-0.111	-0.024
Isapura*	-0.052	0.019	-2.210	0.027	0.160	-0.090	-0.015
voldigi*	-0.034	0.018	-1.260	0.207	0.075	-0.069	0.001
Chototula*	-0.035	0.021	-1.640	0.101	0.336	-0.076	0.007
Risk	0.004	0.005	0.710	0.477	3.914	-0.007	0.014
TimePref*	0.046	0.022	2.080	0.037	0.604	0.003	0.089
obs. P	0.082						
pred. P	.0368091 (at x-bar)						

(*) dF/dx is for discrete change of dummy variable from 0 to 1

z and P>|z| correspond to the test of the underlying coefficient being 0

Number of obs = 268

Pseudo R2 = 0.2297

Log likelihood = -58.600334

LR chi2(12) = 34.94

7. Discussion and Conclusions

The aim of this chapter was to examine the causal effect of economic behaviour on exposure to arsenic technology adoption using experiments in which payoffs vary between choices across time and risk preferences. In relation to risk preferences, it was found that almost half of the respondents are risk averse. Female respondents are more risk averse than male respondents. Also people with higher levels of education are more risk averse. In terms of marital status it was found that single respondents are risk lovers. It should be mentioned that the results of the risk preferences experiment do not appear to have an impact on the adoption of arsenic removal technologies. However, this requires further research. It may be the case that the protocol used to elicit risk preferences needs further adaptation in order to allow the respondents to internalise risk options. Nonetheless, an important result shows that the likelihood of having arsenicosis patients in the family depends negatively of the level of education of the respondent and her risk preferences. More educated respondents may inform their relatives about arsenicosis and are more risk averse so they probably are more familiar with arsenicosis symptoms and arsenic removal technologies and more likely to look for health services.

In relation to other explanatory variables, it was found that gender is a significant variable. In general women are more likely to use filters for drinking water than men. A second important finding is the role of education in arsenic removal technology adoption. More educated respondents are more likely to use a filter (this is consistent with the results found in Chapter 2). The results indicate that an increase in one year of education increases in 3.3% the likelihood of using a filter. A very important result is that the use of filters is also explained by the respondents' time preferences. Respondents with time inconsistent preferences are less likely to use filters. These results are very important since 40% of the respondents showed preference reversals. Those individuals are more likely to procrastinate in the use of filters and thus are more likely to get arsenic related diseases. These results have some important policy implications. People with time inconsistent preferences could be prompted to the use their filters by the implementation of temporal incentive schemes, which reward agents based on when they complete their task (the use of arsenic removal technologies). Following Ambec and Treich (2007), people with limited self-control can sign binding financial agreements among themselves forming coalitions. The financial agreements may help them to alleviate their self-control problems. Finally, it should be mentioned that although income is an important variable to explain the use of arsenic removal technologies (as exposed in chapter 2), other important variables such as education, gender and time preferences are equally important and should be taken into account when designing public policy tools to tackle the challenges posed by groundwater contamination in Bangladesh.

Acknowledgements

The author would like to thank to Dr. Shahnaz Huq Hussain for her advice and support during the fieldwork in Bangladesh. This research was funded by Consejo Nacional de Ciencia y Tecnología (CONACYT México), Dirección General de Relaciones Internacionales – Secretaría de Educación Pública (DGRI – SEP México), the Royal Economic Society Small Academic Expenses Grant and the SOAS Centre Based Research grant for research (Centre for Development, Environment and Policy).

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Appendix A Structural Questionnaire for Quantitative Analysis

Folio:

Food Security and Water Arsenic Contamination
PhD in Economics Project
Economics Department University of London - SOAS

Researcher: Osiel González Dávila
Enumerator:

	Day	Month	Year
1. Date			2012

Zila	Chandpur		Upazila	Shahrasti

2. Village	

3. For how long have you been living in Shahrasti?	Years	

4. Gender /	Female	Male

5. Age	Years	

6. Marital Status	Single	Married	Divorced	Widow	Widower	Spouse Disappeared

7. Household Members	
8. Number of children in the household	

9. Education (C or I)	No education	Primary school	SSC secondary school	HSC Higher Secondary Certificate	Graduate Education	Post Graduate

10. Housing	Pacca	Semi Pacca	All tin	Kutcha	Jhupri	Others

11. Main Source of income									
Agriculture	Fishery	Commerce	Transport	Services	Government employee	Teacher	Doctor	Advocate	Others

12. Household Monthly Income (Tk)	13. Monthly expenditure in food	14. Do you produce your own food?

15. What is your main drinking water source?	Hand tube well	Deep tube well	Pond	Other

16. How many times is water collected for the household per day?	

17. Is your drinking water supply arsenic contaminated?	Yes	No	Do not know

18. Do you drink hand tube well water?	Yes/No

19. If yes, what is the reason?	

20. Do you use a filter for your water?	

21. What kind of filter?	

22. Do you use a CBARU? How many times per month?	

23. If not daily, could you please tell me the reason?	

24. Is the CBARU far from home?	Yes/No

25. Minutes walking	

26. Would you go more often if it was closer?	Yes/No

27. Minutes walking	

28. Do you know about the Arsenic disease (arsenicosis)?	Yes	No
29. Do you know the symptoms of arsenicosis?	Yes	No

30. Do you think your source of drinking water will provoke you arsenicosis?	Yes	No

31. Are there arsenicosis patients in your family?	
Yes	No

32.a Sex	Number	32.b Sex	Number
Female		Male	

34. Time preference experiment answer (Short run)	
35. Time preference experiment answer (Long run)	
36. Risk preference experiment answer	

Appendix B Time preferences in the short term

	Tomorrow		In 1 week	
1		Tk 50	Tk52	
2		Tk 50	Tk55	
3		Tk 50	Tk60	
4		Tk 50	Tk70	
5		Tk 50	Tk100	
6		Tk 50	Tk150	

Appendix C Time preferences in the long term

Tomorrow **In 6 months**

1  Tk 50 Tk55 

2  Tk 50 Tk124 

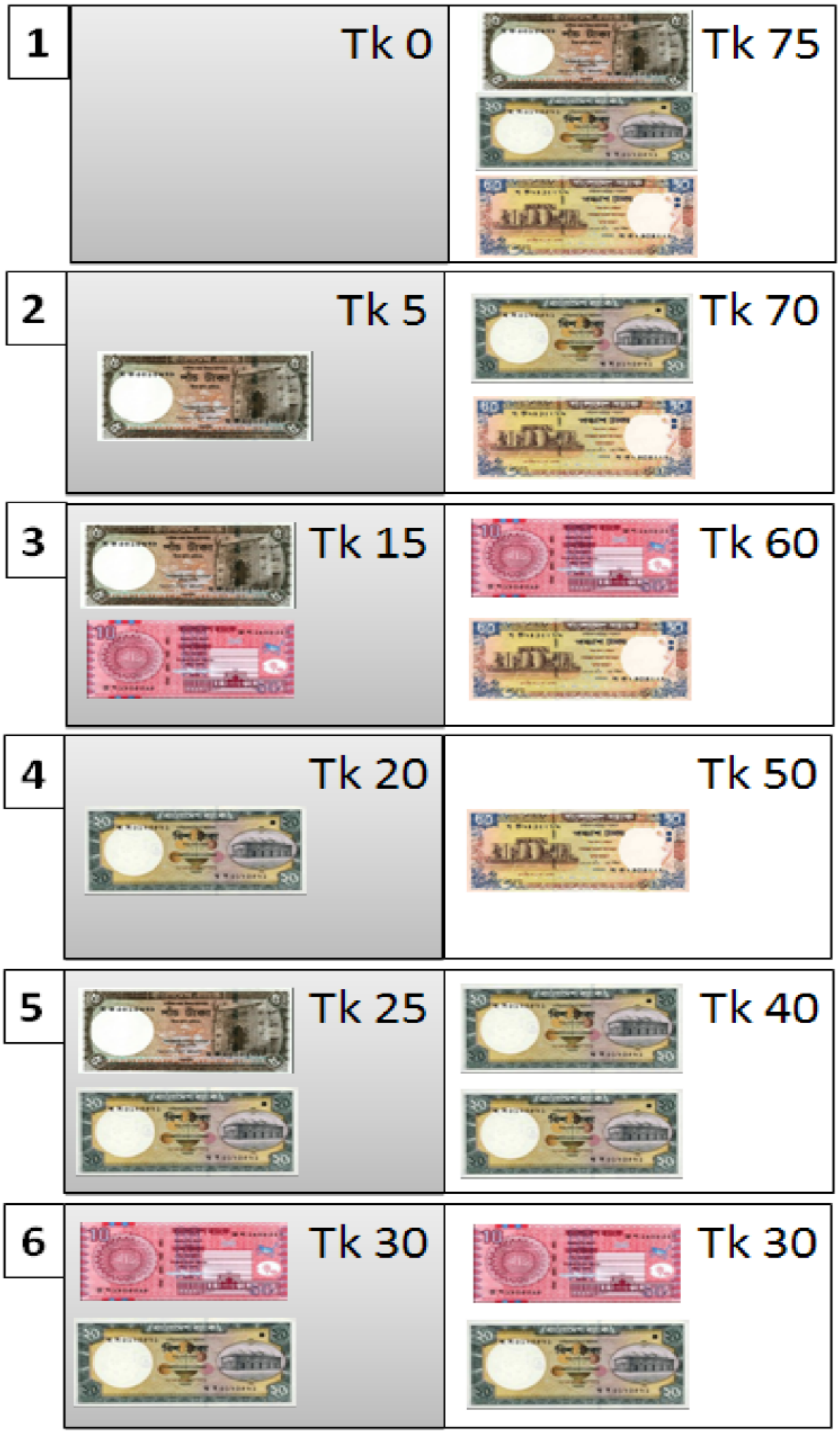
3  Tk 50 Tk240 

4  Tk 50 Tk430 

5  Tk 50 Tk900 

6  Tk 50 Tk1400 

Appendix D Risk preferences



B. Groundwater Contamination in Mexico

Chapter 1

Arsenic and Fluoride Groundwater Contamination in Zacatecas, Mexico: An Introduction

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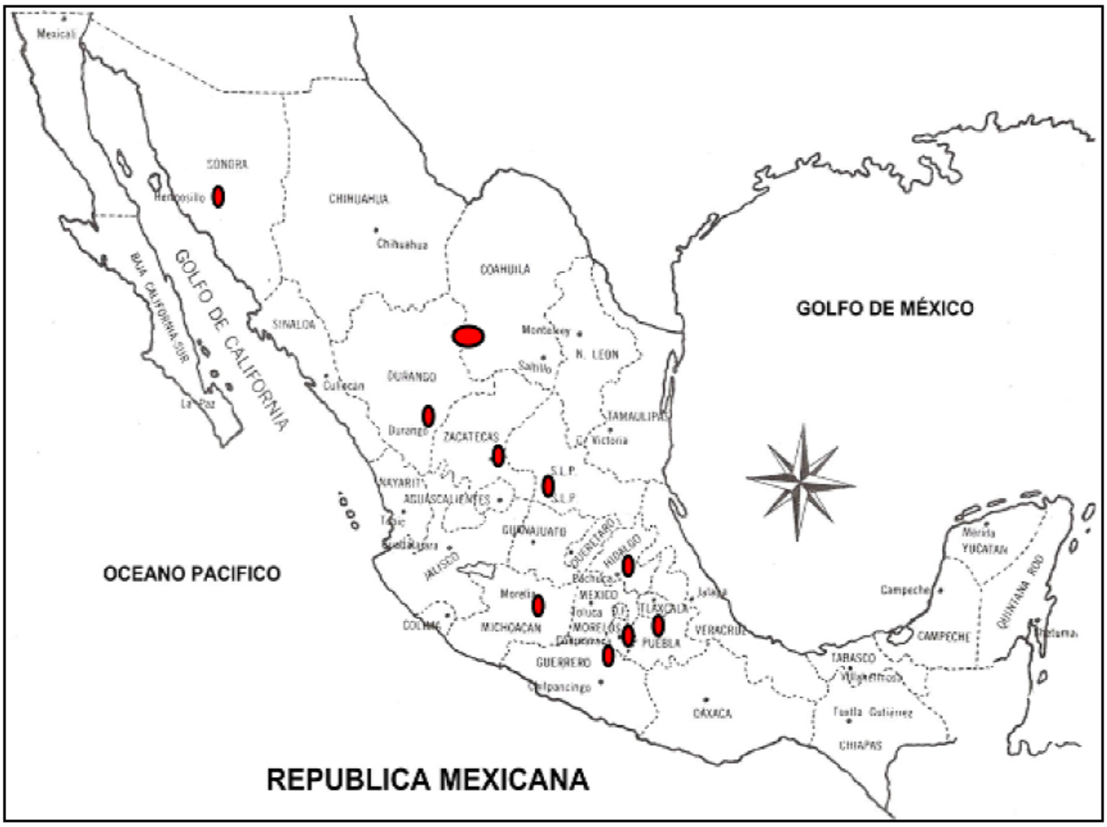
Introduction

This research has its origins in my previous work on groundwater contamination. After conducting research on food security and water contamination in four areas of Bangladesh for my Master's degree, I started wondering if arsenic groundwater contamination was a problem in Mexico. First, it was necessary to identify geographically the places in Mexico that are affected by arsenic contamination of groundwater. The next step was to conduct a review of the previous research on the subject.

1. Previous Research Conducted on Arsenic Contamination in Mexico

The National Commission of Water has calculated that 6.4 million Mexicans live in states where there is systematic information about high levels of Arsenic and/or Fluoride in the waterworks (Vega 2001). Figure 1 shows the groundwater arsenic contaminated areas identified by Méndez and Armienta (2003) and Castro (2006). They include Comarca Lagunera (Durango-Coahuila states), Los Azufres (Michoacán), Durango (Durango), Hermosillo (Sonora), Zacatecas (Zacatecas), Acámbaro (Guanajuato), Puebla (Puebla), Cuautla (Morelos), Delicias (Chihuahua), Zimapán (Hidalgo) and Taxco (Guerrero). Armienta and Segovia (2008) state that there is evidence that water arsenic contamination is due to mining activities in the states of Hidalgo, Baja California and San Luis Potosí. Arsenic is considered to be naturally occurring in the rest of the states. As I explain in chapters 2 and 4, plants and soil contamination with heavy metals in my study area is related to the mining history of the region and the reckless management of new mine tailings. It is possible that the high levels of arsenic in drinking water in Zacatecas have their origins at least in part in mining activities. However, more research is required in order to identify the exact source of contamination in the four different aquifers that supply the area with water. Previous research on groundwater arsenic contamination has been conducted mainly in "Comarca Lagunera" zone. Geophysical, toxicological and biochemical analyses are the most common studies on water arsenic contamination conducted there (see for example García *et al* (1994), Rosas *et al* (1997), Hernández-Zavala *et al* (1998), Del Razo *et al* (2002), Pineda-Zavaleta *et al* (2004) and Coronado González (2007)).

Figure 1 Water Arsenic Contamination in Mexico



Source: Author's elaboration with information contained in Castro (2006) and Méndez and Armienta (2003)

In Mexico, the socio-economics of water arsenic contamination is little studied. To overcome this, the fieldwork that I originally proposed to my PhD supervisor and upgrade committee included a baseline survey in rural communities of the Comarca

Lagunera where the population has been affected by arsenicosis due to the high concentrations of arsenic in the water. It is important to mention that I did not conduct research in Comarca Lagunera but in two municipalities of Zacatecas. The main reason for this was the high levels of drug related violence registered in Comarca in the weeks previous to the fieldwork.

2. Research Placement in Mexico

In September 2010, I had a research placement in the Geophysics Institute at the National Autonomous University of Mexico (UNAM) under the supervision of Dr. María Aurora Armienta. After a grey literature review and a discussion with Dr. Armienta, I decided that Zacatecas was a very interesting place for conducting research due to the fact that only 2 documents (Leal and Gelover 2002 and Castro *et al* 2003) mentioned and measured the levels of arsenic in some of the water extraction wells that feed Zacatecas' capital city and its metropolitan area. Unlike Comarca Lagunera, the impact of water contamination on Zacatecas' population has been little studied. To the best of my knowledge, no other research on the socio-economics of water arsenic contamination has been conducted in Zacatecas. In order to conduct my research I proposed the following research questions:

a) Are the population and the local water management authorities aware of the problem?
b) Do they use arsenic removal technologies?
c) What kind of technology do they use?
d) Is the outcome satisfactory?

3. Exploratory Study and Contingent Valuation of Safe Drinking Water

As it is explained in the exploratory study (see section 5 in chapter 2), the idea was to measure the levels of ***As*** and $\boldsymbol{F^-}$ in the groundwater of the region and to understand the population's level of awareness, health impact and potential arsenic avoidance strategies. The exploratory study gave me a very good insight into the problem and I was able to answer all the research questions. During an interview with the local water management authorities, they stated that they are aware of the problem. However, they do not use any arsenic removal technologies. They mix water from highly contaminated wells with water from less contaminated wells in order to reduce the arsenic contents. This procedure has also been followed in other arsenic contaminated areas like Comarca Lagunera and Zimapán, Hidalgo (García *et al* 1994, Armienta and Segovia 2008). On the other hand, the population is not aware of the high levels of arsenic and fluoride in their tap water. The outcome of this policy (or better yet, lack of policy) is very worrying (see section 5.3 in chapter 2). An important part of the survey was dedicated to find food and water consumption patterns in the study areas. Water samples were collected and analysed in the laboratory in order to determine their arsenic contents. It was decided that fluoride should be included in the research because different studies have identified its presence in various aquifers of Northern Mexico (see Vega 2001 and Armienta *et al* 2010)). In view of the high levels of fluorosis found in the population of the study areas, a complementary survey was conducted asking people if the salt that they use for cooking is fluoridated among other things. A modification of the Mexican Official Norm NOM-040-SSA1-1993 (SSA 2003) established that fluoridated salt should not be distributed in communities where the water has more than 0.7 mg/kg Fluoride. The Norm states clearly that fluoridated salt should not be distributed in Zacatecas. Nevertheless, some respondents stated that they use fluoridated salt for cooking. Having this information, I went to the local markets and found that some retailers sell fluoridated salt in Zacatecas.

It is important to mention that measuring income and food consumption through surveys is a difficult task. There are a number of problems identified and discussed in the literature. For example, problems related to questionnaire design and the ability of interviewees to recall household consumption in different periods of time (for a deep discussion see Deaton 2003). Jones et al (2013), report that different approaches are used in order to measure income and food consumption at individual and household level. For example, in their study in Burkina Faso, Frongillo and Nanama (2006) used total household assets, adult energy intake and child anthropometry. Pérez-Escamilla et al (2004) obtained the probability of daily intake of fruits, vegetables, meat, fish, and dairy for their study in Brazil. Coates et al (2003) and Melgar-Quinonez et al (2006) used total daily per capita food expenditures. For their study in Tanzania, Knueppel et al (2010) measured household wealth status, animal-source food consumption and maternal education. Finally, Deitchler et al (2010) used a household wealth score and net income per consumption unit. All these approaches have their own challenges. I faced some difficulties during the fieldwork in Mexico. Some interviewees refused to disclose information about the level of household income or the main economic activity of the head of the household. The reason is that kidnapping and burglary are prevalent in the region. Other alternatives like measurement of wealth via assets were not considered appropriate because the interviewees were not willing to share this information. Household expenditure on food was considered a better alternative because the interviewees were more comfortable discussing this information with me.

The final part of my research is concerned with the implementation of public policies for the mitigation of the effects of arsenic and fluoride detected in the study area. Therefore, a contingent valuation survey was used to elicit household willingness to pay for safe drinking water in Guadalupe (see section 6 in chapter 2). The objective was to investigate households' willingness to pay (WTP) for improved water quality through the installation of a new filtration system to remove fluoride and arsenic from groundwater. It was found that individuals' subjective perceptions of contamination might change their attitude towards the installation of water purification systems, thereby changing the effective price of potable groundwater that they are willing to pay. It is evident that different types and levels of contamination (by arsenic and fluoride in this case) had differing effects on values. Further, value estimates also changed as the socioeconomic profiles of survey respondents changed. It was found that the respondents stated on average a higher WTP for the removal of fluoride than for the removal of arsenic.

4. Assessment of the Exposure to Arsenic and Fluoride

Once the laboratory results were available, and due to the high levels of arsenic and fluoride found in tap and well water samples (Annex 1) I decided that it was necessary to conduct an assessment of the exposure to arsenic and fluoride from drinking water in the city of Guadalupe, Zacatecas (Annex 2). After the initial findings, there was an urgent need to characterize the risk areas. Therefore, arsenic and fluoride exposures from drinking water were estimated and different risk areas in the city of Guadalupe were identified and mapped. It was found that 100% of the water samples collected in households show levels of arsenic above the Mexican guideline of 0.025 mg/l arsenic and almost 50% of the samples have levels of fluoride above the 1.5 mg/l fluoride guideline. Women and children 0-12 years old were identified as particularly vulnerable groups.

5. Plants and Soil Contamination with Heavy Metals

I also considered it very important to identify other sources of exposure to Arsenic. In the literature it is widely accepted that a common way of arsenic exposure is the consumption of arsenic contaminated food. Therefore, a study on plants and soil contamination with heavy metals in agricultural areas of Guadalupe was conducted in collaboration with some colleagues of the Geophysics Institute in Mexico (see Annex 2). High levels of arsenic, lead and mercury contamination in agricultural soil were found in two irrigation zones. High levels of zinc and copper were found both in soils and plants in all the areas. Heavy metal absorption in maize plants aimed for human consumption was calculated using the bioconcentration and the translocation factors. The accumulation of arsenic and lead in plants was very high. Those elements are highly toxic and could be bioaccumulated and transferred to the food chain. It was also found that new mine tailings in the area are recklessly managed and there is an alarming lack of enforcement mechanisms to oblige the mining companies to obey the environmental laws and regulations. Those new tailings are undoubtedly a source of heavy metal contamination of the neighbouring agricultural land. This should be considered as a threat to health and food safety of the people in the region.

6. Research Dissemination

An early version of the article “Water Arsenic and Fluoride Contamination in Zacatecas Mexico: An Exploratory Study” was presented in the 8th International Conference "Developments in Economic Theory" at the Department of Applied Economics V, University of the Basque Country (Spain), the 1st of July 2011 (see Dávila 2011). A more recent version including the contingent valuation section is available at the SOAS Department of Economics Working Paper Series (see Dávila 2013). The article “Plants and soil contamination with heavy metals in agricultural areas of Guadalupe, Zacatecas, Mexico” was published as a book chapter in the book

Environmental Contamination and is freely available on-line (see Dávila, Gómez-Bernal and Ruíz-Huerta 2012). The article "Assessment of the Exposure to Arsenic and Fluoride from Drinking Water in the City of Guadalupe, Zacatecas, Mexico" was presented in the World Congress on Water, Climate and Energy organised by the International Water Association. This congress was held in Dublin in May 2012 and the paper is freely available on-line (see Dávila 2012).

7. Structure of the Second Section

The following chapters present the results of my research in chronological order. Chapter 2 contains the exploratory study on water arsenic and fluoride contamination in Zacatecas Mexico and a contingent valuation of safe groundwater in Guadalupe. Annex 1 contains the assessment of the exposure to arsenic and fluoride from drinking water in Guadalupe, Zacatecas. The study of maize plants and soil contamination with heavy metals in agricultural areas of Guadalupe is presented in Annex 2.

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Chapter 2

Groundwater Contamination and Contingent Valuation of Safe Drinking Water in Guadalupe, Zacatecas, Mexico

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Abstract

Guadalupe municipality, located in a semi-arid zone, belongs to the State of Zacatecas in north-central Mexico. The population in Guadalupe has been increasing in an exponential way from the year 2000 to 2010. With a bigger population in the area more services are required, including water supply and sanitation. Guadalupe depends on groundwater for its domestic water supply. It has no access to surface water and its aquifers are overexploited. There is a high risk that in the near future the population's water demand could not be satisfied. In addition, high levels of fluoride and arsenic were found in extraction wells and in tap water in Guadalupe City. This may seriously affect the population's health. Women and children 0-12 years old have been identified as particularly vulnerable groups. An exploratory study found statistically significant correlations between the presence of arsenicosis and fluorosis symptoms and the consumption of tap water. A contingent valuation survey is used to investigate households' willingness to pay for improved water quality through the installation of a new filtration system to remove fluoride and arsenic from groundwater. It was found that individuals' subjective perceptions of contamination might change their attitude towards the installation of water purification systems, thereby changing the effective price of potable groundwater that they are willing to pay. It is evident that different types of contamination (by arsenic and fluoride in this case) had differing effects on values. Value estimates also changed as the socioeconomic profiles of survey respondents changed. Finally, respondents on average are willing to pay MXN 51.88 for fluoride removal and MXN 61.79 for arsenic the removal.

Keywords: Groundwater contamination, Arsenic, Fluoride, Contingent Valuation, Zacatecas Mexico.

Introduction

Groundwater plays a very important role on Mexican economic activities and welfare. There are 653 aquifers and on average groundwater extraction provides more than 60% of the national water supply (CONAGUA 2010:68). Arsenic (***As***) and fluoride (***F^-***) have been identified among the most severe inorganic contaminants present in groundwater worldwide (Fawell and Nieuwenhuijsen 2003, Ng *et al*. 2003). Exploitation of aquifers containing toxic elements may increase their concentration, and seriously affect the population's health (Armienta and Segovia 2008:345). Groundwater ***As*** and ***F^-*** levels above the limits established by the Mexican Official Norm (***MON***) have been detected in several areas of Mexico, mainly within the states located on a mineralized belt that crosses from the northwest to the south of the country (Armienta *et al* 2010:61).

According to the National Commission of Water, the total population living in states where there is systematic information about high levels of ***As*** and/or ***F^-*** in the waterworks is 6.4 million people (Vega 2001:3). In Mexico, the association between consumption of water containing high levels of ***As*** and ***F^-*** and adverse health outcomes has been demonstrated in various epidemiological studies (see for example Cebrián *et al.* 1994, Del Razo *et al* 1999, and Armienta *et al* 2010). Armienta and Segovia (2008:351), state that the results of these investigations have prompted the water authorities in some of the affected areas of Mexico to supply water from non-contaminated sources. Nevertheless, these studies have been conducted only in few zones. Therefore, the exposed population may be larger than that already identified and there is an urgent need to conduct similar studies in all contaminated areas.

The research presented in this chapter was carried out in three stages. In the first research stage, an exploratory study was conducted. In Mexico, the socio-economics of groundwater arsenic and fluoride occurrence is little studied and the literature on the topic is scarce. A couple of documents (Leal and Gelover 2002 and Castro *et al* 2003) reported high concentrations of ***As*** and ***F^-*** in groundwater samples of Zacatecas, Mexico. This information was the starting point of the research. Therefore, a baseline survey in two potentially affected municipalities of Zacatecas was undertaken to understand the level of awareness, health impact and potential arsenic and fluoride avoidance strategies. Water samples from extraction wells supplying water to those municipalities were collected and tested for ***As*** and ***F^-*** as part of this exploratory study. High levels of fluoride and arsenic in water samples were found. At the same time, 41% of households in the sample reported brown mottling of teeth (fluorosis symptom) and 18% reported dark spots on the hand palms (arsenicosis symptom) in at least one household member. These results were the starting point of the second stage of the research.

In the second stage two research activities were carried out. First, arsenic and fluoride exposures from drinking water were estimated. Therefore, different risk areas in the city of Guadalupe, Zacatecas were identified and mapped. The resulting research paper is included in Annex 1. Second, a geochemical comparative study was conducted in agricultural areas of Guadalupe. High levels of arsenic, lead and mercury contamination in agricultural soil were found in two irrigation zones. Heavy metal absorption in maize plants aimed for human consumption was calculated using the bioconcentration and the translocation factors. The accumulation of lead and arsenic in maize plants was very high. Those metals are highly toxic and could be bioaccumulated and transferred to the food chain. The resulting research paper is included in Annex 2. In the third and final stage of this research, it was decided to conduct a contingent valuation of safe and reliable groundwater.

The rest of the chapter is organised in the following way: Sections 1 and 2 describe fluoride and arsenic features and their impact on human health. ***As*** and $\boldsymbol{F^-}$ guidelines and standards, both in Mexico and worldwide, are also discussed there. Sections 3 and 4 present a brief review of the Fluorite and Arsenic mining activities in Mexico and the specific mining activities in the state of Zacatecas. Section 5 presents the exploratory study. Section 6 presents the contingent valuation study. Conclusions and policy recommendations are offered in the last section. Annex 1 and 2 present the additional multidisciplinary research papers produced during the second research stage.

1. Fluoride

Fluorine (***F***) is a poisonous gaseous element. In the periodic table of elements it is located in the halogen group (group VIIB). ***F*** is one of the most reactive chemical elements. Therefore, it is not found free in the environment. It has a strong tendency to acquire a negative charge, and in solution forms fluoride ($\boldsymbol{F^-}$) ions. Thus, fluorine in the environment is found as fluorides. Hydroxide ions have the same charge and nearly the same radius as $\boldsymbol{F^-}$ ions and in mineral structures may replace each other.

Thus, F^- forms mineral complexes and some common mineral species of low solubility contain F^- (Fawell *et al* 2006:5). In various places of the world, the presence of F^- in groundwater is a serious cause of morbidity. Dental fluorosis -an unsightly brown mottling of teeth- can result from high F^- intakes. Higher intakes can provoke skeletal fluorosis, which can lead to fractures and crippling skeletal deformity. Fawell and Nieuwenhuijsen (2003:203), report that "fluorosis can manifest itself at an early age with the result that affected individuals cannot work properly and may be economically as well as physically disadvantaged for life." Many factors appear to influence the risk of such adverse effects, including volume of drinking water, nutritional status and, fluoride intake from other sources. High fluoride content of groundwater has caused teeth and bone diseases in San Luis Potosí and Aguascalientes states, both in Central México (Armienta and Segovia 2008:346).

1.1 Fluoride guidelines and standards

In 1984, the first edition of the World Health Organization (WHO) Guidelines for Drinking-water Quality stated that dental fluorosis is associated with fluoride levels in drinking water above 1.5 mg/L. When F^- levels exceed 10 mg/L crippling skeletal fluorosis and an increased risk of bone fractures can result. Thus, a guideline value of 1.5 mg/L F^- was recommended as a level at which dental fluorosis should be minimal (WHO, 1984). The 1984 guideline value was re-evaluated in 1996 and 2004 and it was concluded that there was no evidence to suggest that it should be revised (WHO, 1996, 2004). However, the 1.5 mg/L F^- guideline is not a "fixed" value. If national standards for fluoride are set, they should be adapted to take into account the local conditions for example water intake, climatic conditions, and intake of F^- from food and air (WHO, 1996). In Mexico, a modification in the year 2000 of the Mexican Official Norm NOM-127-SSA1-1994 (SSA 2000:77) established at 1.5 mg/L the permissible limit of F^- in drinking water.

2. Arsenic

Arsenic (***As***) is a member of group VA of the periodic table and has the common oxidation states of –3, +3 and +5. The redox states of ***As*** are arsenite ***As***^{III} (H_3AsO_3) and arsenate ***As***^{V} (H_3AsO_4). ***As*** and its compounds are present in trace quantities in all rock, soil, water and air. However, concentrations may be higher in certain areas as a result of weathering and anthropogenic activities (WHO 2001:9 and Yu 2005:213). High ***As*** levels in drinking water may provoke skin, lung and bladder cancer and other adverse effects. Coetaneous changes due to arsenicosis include melanosis (patchy pigmentation of the skin), hyperkeratosis (thickening of the skin), desquamation and in severe cases gangrene. Anaemia and leucopoenia are highly related with chronic ***As*** exposure (Das, Mallick and Sengupta 2003 and WHO 2001). Epidemiological data demonstrate that many local factors are important, including nutritional status. Kozul *et al* (2009) reported that morbidity for mice exposed to influenza A (H1N1) -also known as *Swine Flu*- was significantly higher if they were also exposed to ***As*** contaminated water than otherwise. They concluded that ***As*** exposure disrupts the immune system and the endocrine system. In Mexico, the ability to have an immune response to influenza A (H1N1) infection was compromised by low levels of arsenic exposure from contaminated well water. It was noted that Mexico has areas of high arsenic in well water that include locations where influenza A (H1N1) was first identified (US Geological Survey 2011:21). The "Comarca Lagunera" is a metropolitan area located between the states of Coahuila and Durango in Northern Mexico. There, high levels of arsenic in drinking water were identified for the first time in 1958 as the cause of adverse effects on health (Cebrián *et al*. 1994). Arsenic levels above the Mexican drinking water standards have also been detected at other locations in Mexico.

2.1 Arsenic guidelines and standards

According to the last edition of the WHO Guidelines for Drinking–Water Quality (2006) ***As*** is considered to be a high–priority substance for screening in drinking–water sources. The current guideline value of 0.01 mg/L ***As*** was retained and designated as provisional since 1993. This value is higher in Mexico. From 1994 until the year 2000, the drinking water standard was 0.05 mg/L ***As.*** A modification to the Mexican Official Norm NOM-127-SSA1-1994 (SSA 2000:77) established since 2005 a guideline value of 0.025 mg/L ***As***.

3. Fluorite and Arsenic in mining zones of Mexico

Mexico is one of the most important arsenic and fluorite producers in the world due to the abundance of these elements in its subsoil. In 2010, Mexico occupied the sixth place in arsenic production (U.S. Geological Survey, 2011:20). Fluorite is one of the main non-metallic minerals exploited in Mexico, mostly in Coahuila, Durango, and San Luis Potosí states. In 2010 Mexico occupied the world's second place in fluorite production (U.S. Geological Survey, 2011:57). In many mining areas of Mexico ***As*** minerals occur in association with ores. Notable occurrences of ***As***-bearing minerals have been reported in various locations. Extraction and processing of ores may be a source of ***As*** contamination (Armienta and Segovia 2008:349). There is consensus in the literature that ***As*** and $\boldsymbol{F^-}$ groundwater contamination is related to mining activities. Mine tailings' environmental impact has been largely documented around the world. Deterioration and contamination of soils, groundwater and superficial water as well as alterations in the hydrological systems have been associated with mining wastes (Figueroa *et al* 2010).

4. Mining activities in Zacatecas

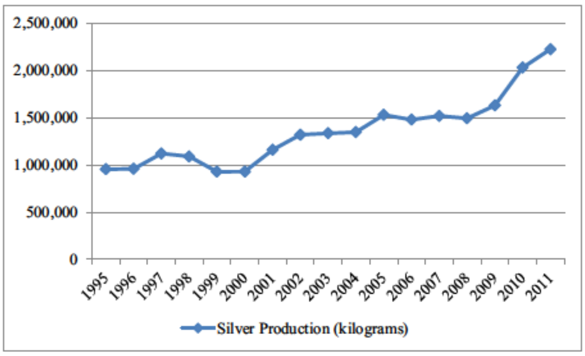
Zacatecas state is located in central north Mexico. There, metallic ores are abundant and diverse. The state has 450 years of mining tradition with the consequent accumulation of mining tailings (Salas–Luévano *et al* 2009). Zacatecas state is the most important silver producer in Mexico. Amalgamation for silver extraction, also known as patio process, consists in adding mercury to the silver ore in order to obtain a silver amalgam as the final product. Amalgamation was used extensively throughout the period from 1570 to 1820. Most of the heavy metals lost via amalgamation were carried by rivers and deposited in the plain areas of the Zacatecan valley in the Guadalupe County. Most of these areas are currently used for crop farming since there are no restrictions imposed by the Mexican authorities (Santos–Santos *et al* 2006). Numerous historic and present mine tailings are found throughout the state with thicknesses that range from less than one meter to ten meters (Castro *et al* 2003:255). Table 1 shows the principal mining products in Zacatecas. It should be noted the steady increase in silver and lead production and the exponential increase in gold production (see figures 1, 2 and 3). Gold mining in Zacatecas could be identified as a potential source of ***As***-contamination of soils and water in the region. Gold mining activities discharge arsenic to the environment through waste soil and rocks, residual water from ore concentrations, roasting of some types of gold-containing ores to remove sulphur and sulphur oxides, and bacterially enhanced leaching (Eisler 2004:133).

Table 1 Minerals production in Zacatecas

Year	Gold Production (kilograms)	Silver Production (kilograms)	Lead Production (tons)
1995	623.9	952,931	51,613
1996	972.8	957,491	57,556
1997	1,160.00	1,118,868	60,952
1998	1,219.90	1,088,406	50,620
1999	1,208.20	926,401	23,438
2000	1,024.00	928,378	19,351
2001	1,078.80	1,158,578	27,077
2002	1,020.60	1,318,425	41,195
2003	1,002.50	1,333,499	50,274
2004	1,185.90	1,345,130	51,904
2005	1,413.70	1,528,765	52,330
2006	1,441.00	1,477,601	46,359
2007	1,295.50	1,517,185	46,044
2008	1,766.50	1,491,525	43,643
2009	6,099.50	1,627,847	50,972
2010	12,836.70	2,028,766	97,789
2011	17,000.20	2,222,538	125,190

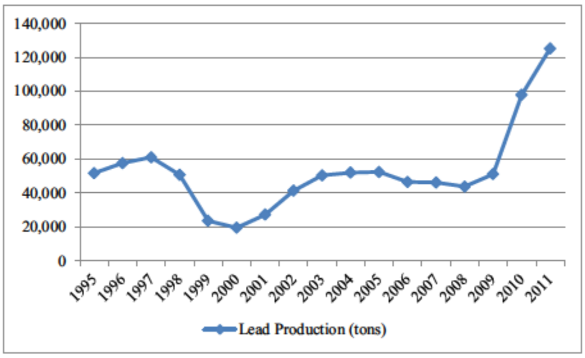
Source: INEGI. Banco de Información Económica 2011

Fig 1 Silver Production in Zacatecas



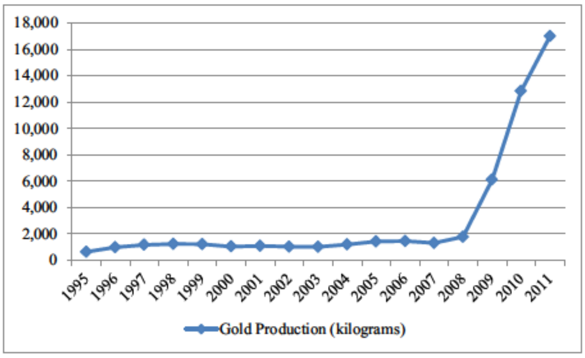
Source: INEGI. Banco de Información Económica 2011

Fig 2 Lead Production in Zacatecas



Source: INEGI. Banco de Información Económica 2011

Fig 3 Gold Production in Zacatecas



Source: INEGI. Banco de Información Económica 2011

4.1 Plants and soil contamination due to mining activities in Zacatecas.

In their exploratory study, Santos–Santos *et al* (2006) reported that the main source of heavy metal contamination in Guadalupe's soil is related to old mining activities carried out in the surrounding area of Osiris and La Zacatecana. However, *Dávila,* Gómez-Bernal and Ruíz-Huerta (2012) report that new mine tailings in the area are recklessly managed and there is an alarming lack of enforcement mechanisms to oblige the mining companies to obey the environmental laws and regulations (see Annex 2). Those new tailings are a source of heavy metal contamination of the neighbouring agricultural land. High levels of arsenic, lead and mercury contamination in agricultural soil and plants were found in two irrigation zones. Two heavy metal exposition routes were identified. In the first place, there is a respiratory intake of particles and dust from contaminated soil. Second, there is a deposition of heavy metals in maize aimed for human consumption in the area. There is also a very high risk of aquifer contamination due to the presence of new tailing ponds in the area. However, more research needs to be done in order to confirm or reject the link between current and old mining activities and aquifer contamination.

5. Exploratory study

This exploratory study was the first stage of the research on groundwater contamination in Mexico. At first, possible research locations were identified in northern states of the country (see Table 2). However, conducting fieldwork in northern Mexico at the time was unfeasible due to security concerns for the researcher. Therefore, it was decided to conduct research in Zacatecas.

Table 2. Arsenic contaminated areas in Mexico

State	Municipality	Population	*As* average concentration (mg/l)
Chihuahua	La Cruz	3,844	0.8
Coahuila	Matamoros	88,235	0.51
Chihuahua	Saucillo	31,042	0.47
Durango	Tlahualilo	22,924	0.29
Chihuahua	San Francisco de Conchos	2,991	0.261
Coahuila	Francisco I. Madero	47,510	0.2
Chihuahua	Julimes	5,335	0.143
Coahuila	San Pedro	91,421	0.14
Chihuahua	Meoqui	38,152	0.13
Chihuahua	Jiménez	39,746	0.103
Hidalgo	Zimapán	38,412	0.09

Source: Author's Elaboration with information contained in Vega (2001)

Although the literature on water contamination in this region is limited, two research papers reported high concentrations of ***As*** and F^- in groundwater samples of Zacatecas (see Leal and Gelover 2002 and Castro *et al* 2003). Thus, an exploratory study was necessary in order to assess the magnitude of the contamination problem and its effects on the local population. The aim of this study was to understand the level of awareness, health impacts and potential ***As*** and F^- avoidance strategies. Therefore, the following research questions were posed:

1. Is the population (and the government) aware of the problem?

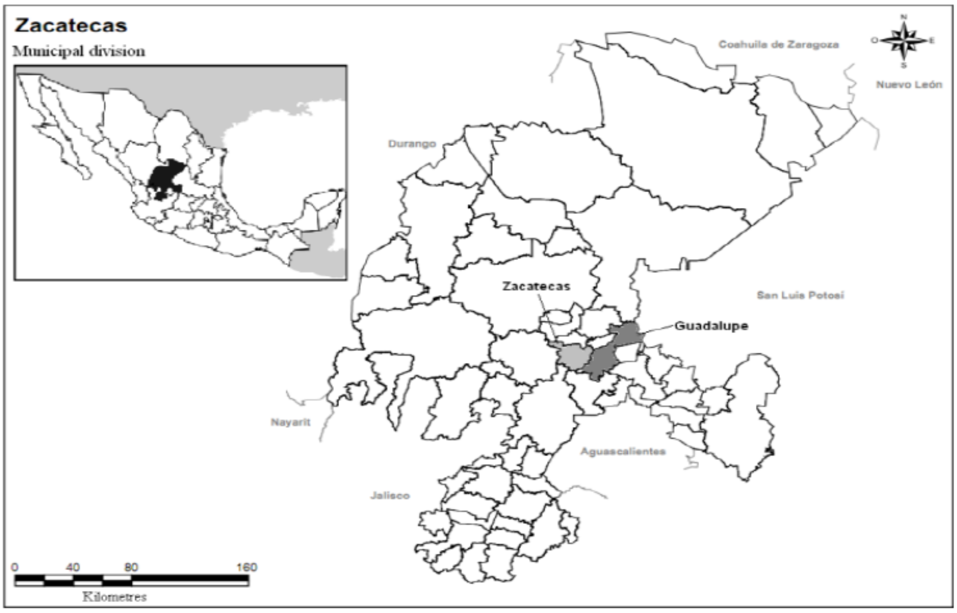
2. Are they using ***As***-removal technologies?
3. What kind of technology?
4. Have the outcomes been satisfactory?

The fieldwork was conducted during September 2010. A baseline survey in two potentially affected municipalities of Zacatecas, Mexico was undertaken. In addition, water samples from extraction wells supplying water to those municipalities were collected and tested for arsenic and fluoride levels as part of this exploratory study. The following sections explain in detail the methodologies employed.

5.1 Geographical delimitation of the study area

Zacatecas and Guadalupe are two municipalities of Zacatecas State in Mexico (see map 1). Zacatecas State is located in a semi-arid zone with an average annual precipitation of 463 mm (CONAGUA 2010:25). The average annual temperature is 17°C. The average maximum temperature is **30°C** and occurs during May. The average minimum temperature is **3°C** and occurs in January. Zacatecas municipality is located at 2,420 metres above sea level (lat 22° 46' N and long 102° 34' O). Guadalupe municipality is located at 2,280 metres above sea level (lat 22° 45' N and long 102° 31' O).

Map 1 Location of Zacatecas and Guadalupe municipalities in Zacatecas State



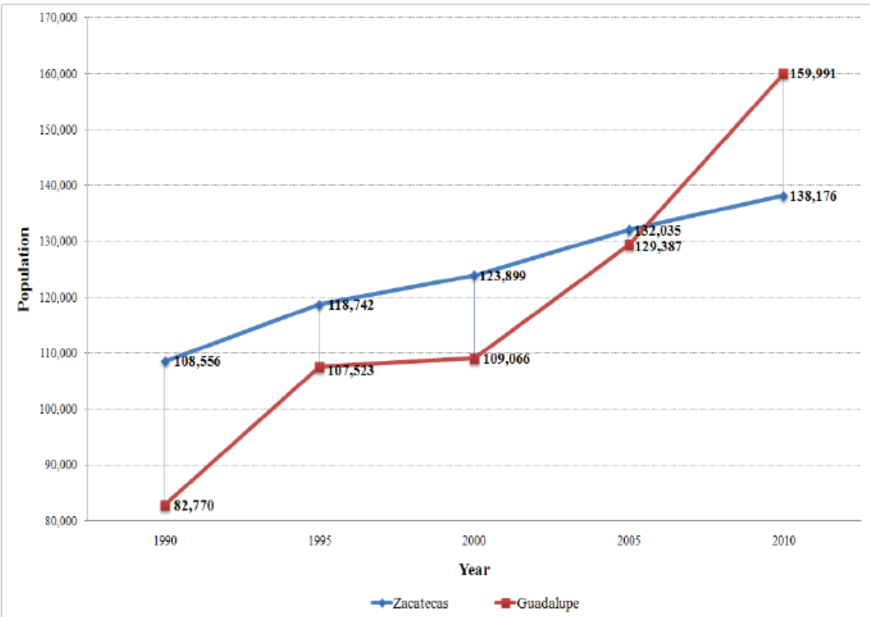
Source: INEGI. Marco Geoestadístico Municipal 2005

The information about altitude of the study area is crucial for understanding fluorosis morbidity in the region. High altitude has been established in the literature as an important risk factor for dental fluorosis. Several studies have found high prevalence and severity of fluorosis in communities located at 1,500 m above sea level. The results suggest that the higher the altitude, the less fluoride is required to cause enamel fluorosis (see for example Angmar-Mansson and Whitford 1990, Molina *et al* 1999, Cao *et al* 2003 or Soto Rojas *et al* 2004).

5.2 Demographic dynamics in the study area and aquifers' exploitation

According to the National Institute of Statistics, Geography and Informatics (INEGI), in the year 2010 Zacatecas had 138,176 inhabitants and Guadalupe 159,991 inhabitants (INEGI 2010). The population in Guadalupe has been increasing in an exponential way from the year 2000 to 2010 (see figure 4). According to the last census Guadalupe's population has exceeded that of Zacatecas (where the capital city is located).

Fig 4 Population in Guadalupe and Zacatecas municipalities



Source: INEGI (2010)

With a bigger population in the area more services are required, including water supply and sanitation. Four aquifers supply water to the zone: Benito Juárez, Calera, Chupaderos and Guadalupe-Bañuelos. The overexploitation of aquifers provokes regional reduction of groundwater levels, dry wells, higher extraction costs, land subsidence and brackish groundwater. Table 3 shows the use of the aquifers in the study area. In all cases the groundwater extraction is higher than the average annual recharge.[d] Given the reported extraction rates and population growth it will be hard to satisfy the population's water demand in the near future. This is a challenge in terms of sustainable development, defined as a pattern of resource use (the use of aquifers in this case) that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations. Another reason of concern is that exploitation of aquifers containing heavy metals may increase their concentration, and seriously affect the population's health (Armienta and Segovia 2008:345).

Table 3 Aquifers use

Code	Aquifer	R	NCD	AGC	Deficit
3210	Benito Juárez	20.1	0	21.24	**-1.14**
3225	Calera	83.9	1.3	150.37	**-67.75**
3226	Chupaderos	72.8	0	184.83	**-112.03**
3227	Gpe. Bañuelos	10.7	0	12.65	**-1.95**

All figures are expressed in millions of cubic metres per year. R: Average annual recharge; NCD: Natural committed discharge; AGC: Average groundwater concessions. Averages refer to the period 1971-2008.

Source: CONAGUA (2009 and 2010)

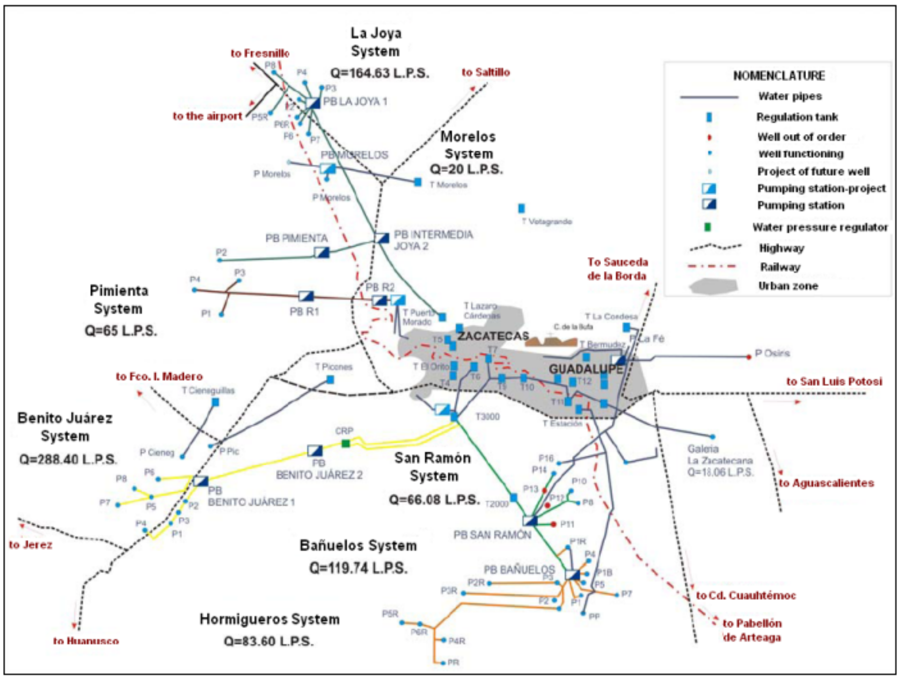
5.3 Identification of arsenic and fluoride levels in the water supply systems

Map 2 shows the water supply systems in the suburban area of Zacatecas and Guadalupe. They can be grouped into three systems. The first system is called "la Joya" or "Calera" and includes one extraction well from the "Pimienta" system and the "Morelos" system. The second system is called "Benito Juárez" and includes three extraction wells from the "Pimienta" system. The third system is called "Bañuelos-San Ramón" and includes the "Hormigueros" system. According to the volume of extracted water, in first place we find the Benito Juárez system that produces 280.77 litres per second (40%); followed by the Bañuelos-San Ramón system that produces 254.84 litres per second (37%) and finally, La Joya system that produces 161.46 litres per second (23%). These systems operate 24 hours per day. The concentration levels of ***As*** in the extraction wells of the region is unevenly distributed and present variations over time. Castro *et al* (2003:259) measured water

[d] The averages reported in CONAGUA (2010) refer to the period 1971-2008.

quality for 48 extraction wells of the three systems in 1994. They reported an ***As*** concentration range from 0.001 to 0. 4925 mg/L. Leal and Gelover (2002:80) sampled 10 extraction wells in the zone. 40% of the samples were above the Mexican guideline of 1.5 mg/L ***F***⁻. 80% of the samples were above the 2005 Mexican guideline of 0.025 mg/L ***As.***

Map 2 Water supply systems in the Zacatecas – Guadalupe zone



Source: Rivera (2010:18)

After analysing the data reported in Leal and Gelover (2002), the San Ramón system was identified as the most problematic water system in the region. Thus, it was decided to collect water samples from the extraction wells of the whole system. Ten samples from the extraction wells San Ramón 8, 10, 14, 16 and "la Coruña" were collected following the methodology in the Mexican Official Norm and tested for ***As*** and ***F***⁻ in the Laboratory of Analytical Chemistry at the Geophysics Institute of the National Autonomous University of Mexico (UNAM). The results are shown in Table 4. In relation to ***As***, extraction well 16 is ten times above the current ***MON*** while extraction well 14 is sixteen times above the guideline. It should be noted that there is a documented variation overtime of both ***As*** and ***F***⁻ contents. Table 5 shows historical ***As*** levels in wells 14 and 16. Table 6 shows historical ***F***⁻ levels in wells 14 and 16. There is an evident increase of the ***F***⁻ levels in such wells. Castro *et al* (2003) report that extraction wells with high ***As*** contents were closed. However, extraction wells 14 and 16 in the San Ramón system (historically showing high levels of ***As*** and ***F***$^-$) were operating normally during the water-sampling period in September 2010. The researcher was informed that extraction well 13 was also fully operating, but permission for taking a sample was denied.

Neither Zacatecas municipality nor Guadalupe municipality have ***As*** and/or ***F***$^-$ water treatment plants. During the fieldwork it was found that the local water authorities mix water from highly contaminated wells with water from others less contaminated as a method to reduce the levels of ***As*** and ***F***$^-$ in the water supply of the region. This method has also been implemented in other water arsenic contaminated areas like Comarca Lagunera and Zimapán, Hidalgo (García *et al* 1994, Armienta and Segovia 2008). In order to evaluate the tap water quality, eight water samples were collected from households in Guadalupe and Zacatecas cities and were tested for ***As*** and ***F***$^-$ (see Table 4). All the samples but one are above the ***As*** and ***F***$^-$ Mexican guideline. All the tap water collected in households belonging to suburban areas of both municipalities have ***As*** concentrations above the WHO guideline of 0.01 mg/L but under the ***MON*** guideline of 0.025 mg/L.

Table 4 As and F$^-$ levels in Guadalupe and Zacatecas extraction wells and households

Sample name	As mg/L	F^- mg/L
San Ramón 8	0.0154	1.26
San Ramón 10	0.0216	1.36
San Ramón 14	0.4072	3.09
San Ramón 16	0.2920	3.05
San Ramón "La Coruña"	0.0170	1.30
Bañuelos 3	0.0200	1.26
Bañuelos pumping station	0.0180	1.09
Guadalupe household 1	0.0420	1.72
Guadalupe household 2	0.0850	1.45
Zacatecas household 1	0.0400	1.57
Zacatecas household 2	0.0340	1.63
Bañuelos household 1	0.0170	1.27
Bañuelos household 2	0.0180	1.28
San Ramón household	0.0170	1.35
San Jerónimo household	0.0160	1.05
Mexican guideline value	**0.0250**	**1.50**

Table 5 Historical As levels in wells 14 and 16

Sample name	As mg/L Mar-94	Nov-94	2002	Sep-10
San Ramón 14	0.4925	0.138	0.463	0.4072
San Ramón 16	0.356	0.155	0.425	0.292
Mexican guideline value: **0.025**				

Source: Castro, Torres, and Iturbe (2003) and Leal, M. and Gelover, S. (2002)

Table 6 Historical F^- levels in wells 14 and 16

Sample name	F^- mg/L 2002	2010
San Ramón 14	2.92	3.09
San Ramón 16	2.96	3.05
Mexican guideline value: **1.5**		

Source: Leal, M. and Gelover, S. (2002)

5.4 Exploratory Study: Structural Questionnaire for Quantitative Analysis

Primary data was obtained through a pre–tested standardized structural questionnaire for quantitative analysis (see Appendix 1). The aim of the exploratory survey was to understand the level of arsenicosis and fluorosis awareness, health impact and potential ***As*** and ***F***⁻ avoidance strategies of the population in the study area. The researcher and a Mexican research assistant educated at postgraduate level conducted face to face interviews. Training on identification of fluorosis and arsenicosis symptoms was provided. Guadalupe municipality was visited first. Because of the nature of the questionnaires only individuals 18 years old or above were interviewed, preferably the head of household or a mature respondent if the head of household was not available or if the respondent was contacted outside the household. From the 2010 Population Census (INEGI 2010) it was obtained the total population in Guadalupe and Zacatecas municipalities: 298,167 inhabitants. The required sample size[e] was 184 questionnaires.

5.5 Exploratory Study Survey Structure

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[e] It was calculated using the following formula:

$$1)\; n \geq \frac{N\left(\frac{z}{2e}\right)^2}{N-1+\left(\frac{z}{2e}\right)^2}$$

Where n represents the sample size, N the population, z the z–score and e the error, and considering margin of error of less than 10% at a 99% confidence level.

The survey is divided into eight sections. The first section records the time and place of the interview and the number of years that the respondent has lived in the municipality. Only respondents living in Zacatecas and Guadalupe municipalities were interviewed. The second section records the individual details of the respondents: their age and sex. Social information like the marital status of the respondent, the number of household members and the number of children 14 years old and younger were captured in section three. Six variables were selected for registering economic information in section four. Monetary and non-monetary factors that impact the household income were considered. The level of education was included because a higher education level usually is correlated with higher income. The respondent's main economic activity was also asked. The four monetary variables included are: The household income, the household monthly expenditure in food, in bottled water and in household water. All the monetary variables are expressed in Mexican pesos. Section five gathers information about water supply features. Three variables were considered to differentiate the water supply sources according to its use: Drinking water, cooking water and other uses water. It was also asked if the household owns a water filter and the brand of such filter. Finally, it was asked if the respondents have noticed a change in colour or flavour in the tap water in the last three years. The aim of section six is to identify the water consumption patterns in the study sites. Two variables were considered. At individual level the amount of drinking–water glasses consumed per day. It was explained to the respondents that the size of the glass should be one of approximately 250 millilitres. At household level the average litres of water used for cooking per day. Section seven aims to assess the respondent's knowledge of arsenicosis and fluorosis symptoms and the household health status. Questions relative to the presence of brown mottling of teeth (fluorosis symptom) and the presence of dark spots on the hand palms (arsenicosis symptom) of household members were posed. Information about access to health services was also collected. Finally, section eight recorded weekly food consumption patterns in relation to the following items: Soup, beans, chicken soup, stew, coffee and atole. Such items are of particular interest. They could increase the risk of fluorosis and/or arsenicosis symptoms if ***As*** and $\boldsymbol{F^-}$ contaminated water is used in their preparation.

5.6 Average profile of sampled households

Table 7 shows the average profile of sampled households. As previously explained only individuals 18 years old or above were interviewed. The respondents' average age is 38 years. This average is consistent with the survey design because normally mature people are responsible for the household administration. The highest proportion of respondents is concentrated in the 18–29 age group (37.5%), while the lowest is in the group 50-59 years (9.78%). The percentage of female and male respondents is 49% and 51% respectively. Almost sixty percent of respondents are married. This is consistent with the age groups found in the sample. The average number of household members is 4.48 and on average there is one child under 14 in each household. This information is important because research has found that children under 14 are at the highest risk of showing fluorosis symptoms. On average the respondents have 9.22 years of schooling. The average household income is MXN 4,496. The average monthly expenditure in food is MXN 1,573.[f] This means that approximately one third of the household income is used in buying food.

Table 7 Average profile of sampled respondents*

Description	Mean	SD
Age of the respondent (in years)	38.12	16.72
Percentage of female respondents	48.91	50.12%
Education of the respondent (no. of schooling years)	9.22	4.09
Number of household members	4.48	2.28
Number of children (under 14) in the household	1.03	1.27
Marital status (percentage married)	59.24	49.27%
Monthly household income (MXN)	4,496.20	6,269.46
Monthly expenditure in food (MXN)	1,573.22	1,117.08

* 1 USD = 12.40 MXN (2010 average)

Additional socio-economic information is presented in Table 8. The households' income per capita was divided into quintiles. Households in the first quintile have a monthly income per capita equal to or less than MXN 400. On the other hand, households in the higher income category (quintile 5) have a monthly income per capita higher than MXN 1,800. The respondents' average educational attainment (measured in years of schooling) increases with income level. Respondents in the first quintile have on average 7.83 years of schooling while respondents in the fifth

[f] During 2010 the average exchange rate was 1 USD = 12.40 MXN

quintile have 12.47 years of schooling on average. The reported average family size is 6.5 members in the first income quintile and 2.59 in the fifth income quintile. The average number of children under 14 in the household is 1.76 in the first income quintile and 0.28 in the fifth income quintile. In other words, wealthier households have on average a smaller family size and fewer children. It should be noted that 73% of the respondents stated that they have access to health services provided by the state and most of such services provide medicines.

Table 8 Socio-economic information of the surveyed households

Income quintiles	Monthly income per capita range in MXN*	Education (years of schooling)		Family size		Children Under 14	
		Mean	SD	Mean	SD	Mean	SD
1	83-400	7.83	3.28	6.50	2.85	1.76	1.64
2	417-725	9.32	3.75	5.00	1.84	1.23	1.28
3	750-1,000	9.19	4.13	4.21	1.20	1.02	1.02
4	1,040-1,750	11.15	4.84	3.62	1.33	0.68	0.98
5	1,800 and above	12.47	4.18	2.59	1.50	0.28	0.63

* 1 USD = 12.40 MXN (2010 average)

5.7 Analysis of the Relationship between Water and Food Consumption Patterns and Arsenicosis and Fluorosis Symptoms

It is very well established in the literature that ***As*** and ***F***⁻ contamination of drinking water and food items pose a risk for human health (see sections 1 and 2 of this chapter and Annex 1). The aim of this section is to analyse the relationship between water and food consumption at household level and arsenicosis and fluorosis symptoms. The information analysed here was collected in the exploratory study survey (see section 5.5 and Appendix 1). In terms of water consumption, households in the region use a variety of water sources for drinking and cooking (see Table 9). 57.61% of the interviewees stated that in the household they only drink bottled water. In contrast, 18.48% of the respondents stated that tap was their only source of drinking water. The rest of the respondents use a combination of filters, bottled water and tap water. In contrast, tap water is the most important source for cooking water followed by bottled water. 47.48% of the interviewees reported that in their households they only use tap water for cooking and 33% of the respondents use only bottled water for cooking. This difference is central for the subsequent analysis since using tap water for cooking has important health implications.

Table 9. Source of Water Supply (Drinking and Cooking)

Drinking Water	Freq.	Percent	Cooking Water	Freq.	Percent
Bottled	106	57.61	Bottled	61	33.33
Filtered	8	4.35	Filtered	9	4.92
Filtered & Bottled	14	7.61	Filtered & Bottled	4	2.19
Tap	34	18.48	Tap	88	48.09
Tap & Bottled	17	9.24	Tap & Bottled	18	9.84
Tap & Filtered	4	2.17	Tap & Filtered	2	1.09
Well	1	0.54	Well	1	0.55
Total	184	100	Total	183	100

Table 10. Monthly Household Expenditure in Tap and Bottled Water

Description	Mean	SD
Monthly expenditure in tap water (MXN)	91.17	77.59
Monthly expenditure in bottled water (MXN)	104.12	117.96

It was found that households in the region adapt to the existing water supply system conditions by using different averting and private investment choices, among them bottled and home filtered water consumption and the installation of water storage facilities. These revealed behaviors suggest that there is a latent demand for safer and more reliable water services, which was corroborated by the CV survey evidence discussed in section 6. Table 10 shows that the average monthly expenditure in household tap water is MXN 91 and the average monthly expenditure in bottled water is MXN 104. In addition, 27 out of 184 respondents have water filters in their household. However, household filter technologies are usually not adequate for removing fluoride and heavy metals. The mistrust in the quality of tap water could be related to the fact that almost half of the respondents reported changes in the colour (brown or white) and/or flavour (strong chloride or soil flavour) of their tap water in the last 3 years. Access to tap water and water storage tanks is very high. It should be highlighted that 99.5% of the respondents have access to tap water, 43 households in the sample have a water cistern (23%) and 164 have water tanks (89%).

5.7.1 Fluorosis Analysis

Although high levels of fluoride have been found in the water extraction wells of the region (see Leal and Gelover 2002 and Castro *et al* 2003), the population is not aware of the health problems associated with the consumption of fluoride contaminated water. Only 10% of the respondents know what is fluorosis, 7% of the respondents can identify the fluorosis symptoms and only 4% know how to avoid it. A fluorosis dummy variable (FDV) was used to assess the relationship between fluorosis symptoms, water and food consumption and other household characteristics. The variable takes the value of 1 if the household has at least one member with fluorosis symptoms and 0 otherwise. 41.3% of the respondents stated that at least one household member shows brown mottling of teeth (fluorosis symptom). The interviewers verified this directly on 44 respondents. The association between income categories or education attainment of the head of the household and the presence of fluorosis symptoms in at least a household member was investigated. Table 11 presents a cross-tabulation of FDV and categories of income. It shows that 74 households reported at least one member with fluorosis symptoms. 18 out of 42 households in the first quintile and 17 out of 32 households in the fifth quintile reported fluorosis symptoms. The chi-squared value is not statistically significant. A weak positive correlation coefficient between the FDV and the household's level of income was found but it was not statistically significant. Table 12 presents a cross-tabulation of FDV and educational attainment of the head of the household. Again, the chi-squared value is not statistically significant and there is a weak positive correlation coefficient between the FDV and the educational attainment of the head of the household. Thus, the association between fluorosis symptoms and levels of income and educational attainment of the head of the household is not statistically significant.

Table 11. Income Per Capita and FDV

Fluorosis Symptoms	Income per capita quintiles					Total
	1	2	3	4	5	
No	24	19	28	21	15	107
Yes	18	12	14	13	17	74
Total	42	31	42	34	32	181

Pearson chi2 =3.2017 Pr = 0.525
r=0.0475 Pr= 0.5258

Table 12. Education Attainment of the Head of the Household and FDV

Fluorosis Symptoms	Education						Total
	None	Elementary	Secondary	Vocational	High School	University	
No	4	34	26	8	15	21	108
Yes	5	20	11	6	14	20	76
Total	9	54	37	14	29	41	184

Pearson chi2=4.7447 Pr = 0.448
r=0.0599 Pr=0.4195

Further statistical analysis was conducted in order to assess if the presence of brown mottling of teeth in at least one household member is associated with the type of drinking water supply and the type of cooking water supply. It was expected that households using bottled or filtered water would be less likely to present fluorosis symptoms. Dummy variables for each water supply category were created. They take the value of 1 if the respondent uses the relevant source of water and 0 if not. A contingency table approach was used. The risk of reporting fluorosis in each drinking water supply exposure group was estimated from the cumulative incidence. The fluorosis risk ratio was obtained dividing the cumulative incidence in the exposed group by the cumulative incidence in the unexposed group: RR= (CI_e) / (CI_u). Table 13 presents the contingency tables for cooking water sources and the FDV. Households using only tap water for cooking increased in 41% their risk of suffering fluorosis. The estimated chi-squared value is statistically significant. In addition, a positive and statistically significant correlation coefficient between cooking with tap water and suffering fluorosis was found. The rest of the associations were not statistically significant. Table 1 in Appendix 5 presents the contingency tables for drinking water sources and the FDV. The estimated fluorosis risk ratios indicate that households drinking only tap water increase in 42% their risk of suffering fluorosis while households consuming only bottled water increase by 13% their risk of suffering fluorosis. The estimated fluorosis risk ratios for households using a combination of water sources had different percentages of reduction in risk of suffering fluorosis. However, none of the estimated chi-squared values are statistically significant. Thus, the association between drinking water source and fluorosis symptoms in at least one household member is not statistically significant.

Table 13. Contingency Tables for Cooking Water Sources and FDV*

FDV	CW Tap		Total	Cumulative Incidence
	0	1		
0	63	44	107	0.41
1	32	44	76	0.58
Total	95	88	183	
Risk Ratio = 1.41				
Pearson chi2=5.0081	Pr = 0.025		r=0.1654	Pr=0.0252

FDV	CW Bottled		Total	Cumulative Incidence
	0	1		
0	73	34	107	0.32
1	49	27	76	0.36
Total	122	61	183	
Risk Ratio = 1.12				
Pearson chi2 = 0.2813	Pr = 0.596			

FDV	CW Filtered		Total	Cumulative Incidence
	0	1		
0	100	7	107	0.07
1	74	2	76	0.03
Total	174	9	183	
Risk Ratio = 0.40				

FDV	CW Filtered & Bottled		Total	Cumulative Incidence
	0	1		
0	104	3	107	0.03
1	75	1	76	0.01
Total	179	4	183	
Risk Ratio = 0.47				

FDV	CW Tap & Bottled		Total	Cumulative Incidence
	0	1		
0	91	16	107	0.15
1	74	2	76	0.03
Total	165	18	183	
Risk Ratio = 0.18				

FDV	CW Tap & Filtered		Total	Cumulative Incidence
	0	1		
0	105	2	107	0.02
1	76	0	76	0.00
Total	181	2	183	
Risk Ratio = 0				

*The chi-squared test was not performed when a table did not have enough data

Table 14. Contingency Tables for Food Items Cooked with Tap Water and FDV

FDV	Soup Tap 0	Soup Tap 1	Total	Cumulative Incidence
0	70	38	108	0.35
1	38	38	76	0.50
Total	108	76	184	
Risk Ratio 1.42				
Pearson chi2 = 4.0384 Pr = 0.044			r= 0.1481 Pr= 0.0448	

FDV	Beans Tap 0	Beans Tap 1	Total	Cumulative Incidence
0	66	42	108	0.39
1	34	42	76	0.55
Total	100	84	184	
Risk Ratio 1.42				
Pearson chi2 = 4.8206 Pr = 0.028			r= 0.1619 Pr= 0.0282	

FDV	Chicken Soup Tap 0	Chicken Soup Tap 1	Total	Cumulative Incidence
0	66	42	108	0.39
1	39	37	76	0.49
Total	105	79	184	
Risk Ratio 1.25				
Pearson chi2 = 1.7469 Pr = 0.186			r= 0.0974 Pr=0.1882	

FDV	Stew Tap 0	Stew Tap 1	Total	Cumulative Incidence
0	74	34	108	0.31
1	44	32	76	0.42
Total	118	66	184	
Risk Ratio 1.34				
Pearson chi2 = 2.1887 Pr = 0.139				

FDV	Coffee Tap 0	Coffee Tap 1	Total	Cumulative Incidence
0	81	27	108	0.25
1	50	26	76	0.34
Total	131	53	184	
Risk Ratio 1.37				
Pearson chi2 =1.8453 Pr = 0.174				

FDV	Atole Tap 0	Atole Tap 1	Total	Cumulative Incidence
0	79	29	108	0.27
1	62	14	76	0.18
Total	141	43	184	
Risk Ratio 0.69				
Pearson chi2 = 1.7705 Pr = 0.183				

Table 14 shows the contingency tables on each for the food items cooked with tap water. Households consuming soup cooked with tap water increased in 42% their risk of suffering fluorosis. The estimated chi-squared value is statistically significant. In addition, a positive and statistically significant correlation coefficient between consumption of soup cooked with tap water and suffering fluorosis was found. Households consuming beans cooked with tap water also increased in 42% their risk of suffering fluorosis. The chi-squared value is statistically significant and a positive and statistically significant correlation coefficient between consumption of beans cooked with tap water and suffering fluorosis was found. In addition, it was found that reporting fluorosis symptoms is positively correlated with the litres of water used for cooking ($r= 0.1463$ $p= 0.0488$). In view of the high levels of fluorosis found among the population, it was thought that there might be other sources of exposure to fluoride like fluoridated salt. During a visit to local retailers at the end of the exploratory study the researcher found that local retailers were selling fluoridated salt from two different brands: "Sal Cisne" and "Sal La Fina" (see Appendix 4). Thus, a brief complementary survey (see Appendix 2) was conducted asking 112 people if the salt that they use for cooking is fluoridated. A modification to the Mexican Oficial Norm NOM-040-SSA1-1993 established that flouridated should not be distributed in Zacatecas State (SSA 2003). Nevertheless, 9% of the respondents said that they use fluoridated salt for cooking. No further statistical research was conducted using the complementary survey. The amount of households consuming fluoridated salt was not enough to produce statistically significant results.

5.7.2 Arsenicosis Analysis

In general, the local population is not aware of the health problems related with the consumption of arsenic contaminated water. For instance, 78% of the interviewees do not know what arsenic is, 90% do not know the disease caused by arsenic (arsenicosis) and 98% cannot recognise the arsenicosis symptoms. An arsenicosis dummy variable (ADV) was used to conduct further statistical analysis. It takes the value of 1 if the household has at least one member with arsenicosis symptoms and 0 otherwise. It was found that 18.48% of households reported at least one member with dark spots on the hand palms (arsenicosis symptom). Table 15 presents a cross-tabulation of ADV and categories of income. 7 out of 42 households in the first quintile and 2 out of 32 households in the fifth quintile reported arsenicosis symptoms. The estimated chi-squared value and correlation coefficient are not statistically significant. Table 16 presents a cross-tabulation of ADV and educational attainment of the head of the household. Again, the chi-squared value and correlation coefficient are not statistically significant. Therefore, the association between arsenicosis symptoms and levels of income and educational attainment of the head of the household is not statistically significant.

Table 15. Income Per Capita and ADV

ADV	Income per capita quintiles					Total
	1	2	3	4	5	
0	35	25	30	27	30	147
1	7	6	12	7	2	34
Total	42	31	42	34	32	181

Pearson chi2 =6.1351 Pr = 0.189
r = -0.0583 Pr= 0.4357

Table 16. Education Attainment of the Head of the Household and ADV

ADV	Education						Total
	None	Elementary	Secondary	Vocational	High School	University	
0	7	44	27	12	23	37	150
1	2	10	10	2	6	4	34
Total	9	54	37	14	29	41	184

Pearson chi2=4.2070 Pr=0.520
r= -0.0891 Pr=0.2288

The association between arsenicosis symptoms and type of water supply was analysed. Dummy variables for each water supply category were created. They take the value of 1 if the respondent uses the relevant source of water and 0 if not. It was expected that households using bottled or filtered water would be less likely to present arsenicosis symptoms. The risk of reporting arsenicosis in each water supply exposure group was estimated from the cumulative incidence as in the previous section. Table 17 presents the contingency tables for cooking water sources and the ADV. Households using only tap water for cooking increased in 46% their risk of suffering arsenicosis. The estimated chi-squared value is statistically significant. In addition, a positive and statistically significant correlation coefficient between cooking with tap water and suffering fluorosis was found. The rest of the associations in the table were not statistically significant. Table 2 in Appendix 5 presents the contingency tables for drinking water sources and the ADV. None of the estimated the chi-squared values are statistically significant. Thus, the association between drinking water source and arsenicosis symptoms in at least one household member is not statistically significant.

Table 17. Contingency Tables for Cooking Water Sources and ADV*

ADV	CW Tap		Total	Cumulative Incidence
	0	1		
0	83	66	149	0.44
1	12	22	34	0.65
Total	95	88	183	
Risk Ratio = 1.46				
Pearson chi = 4.6198 Pr = 0.032 r=0.158 Pr=0.0317				

ADV	CW Bottled		Total	Cumulative Incidence
	0	1		
0	96	53	149	0.36
1	26	8	34	0.24
Total	122	61	183	
Risk Ratio = 0.66				
Pearson chi2 = 1.8062 Pr = 0.179				

ADV	CW Filtered		Total	Cumulative Incidence
	0	1		
0	140	9	149	0.06
1	34	0	34	0.00
Total	174	9	183	
Risk Ratio = 0.00				

ADV	CW Tap & Filtered		Total	Cumulative Incidence
	0	1		
0	148	1	149	0.01
1	33	1	34	0.03
Total	181	2	183	
Risk Ratio = 4.38				

ADV	CW Tap & Bottled		Total	Cumulative Incidence
	0	1		
0	133	16	149	0.11
1	32	2	34	0.06
Total	165	18	183	
Risk Ratio = 0.55				

ADV	CW Filtered & Bottled		Total	Cumulative Incidence
	0	1		
0	146	3	149	0.02
1	33	1	34	0.03
Total	179	4	183	
Risk Ratio = 1.460784 314				

*The chi-squared test was not performed when a table did not have enough data

Table 18. Contingency Tables for Food Items Cooked with Tap Water and FDV

ADV	Soup Tap 0	Soup Tap 1	Total	Cumulative Incidence
0	92	58	150	0.39
1	16	18	34	0.53
Total	108	76	184	
Risk Ratio 1.37				
Pearson chi2 = 2.3296 Pr = 0.127				

ADV	Beans Tap 0	Beans Tap 1	Total	Cumulative Incidence
0	88	62	150	0.41
1	12	22	34	0.65
Total	100	84	184	
Risk Ratio 1.57				
Pearson chi2 = 6.1027 Pr = 0.013		r= 0.1821 Pr= 0.0134		

ADV	Chicken Soup Tap 0	Chicken Soup Tap 1	Total	Cumulative Incidence
0	89	61	150	0.41
1	16	18	34	0.53
Total	105	79	184	
Risk Ratio 1.30				
Pearson chi2 = 1.7044 Pr = 0.192				

ADV	Stew Tap 0	Stew Tap 1	Total	Cumulative Incidence
0	101	49	150	0.33
1	17	17	34	0.50
Total	118	66	184	
Risk Ratio 1.53				
Pearson chi2 = 3.6201 Pr = 0.057	r=0.1403 Pr= 0.0576			

ADV	Coffee Tap 0	Coffee Tap 1	Total	Cumulative Incidence
0	110	40	150	0.27
1	21	13	34	0.38
Total	131	53	184	
Risk Ratio 1.43				
Pearson chi2 = 1.8089 Pr = 0.179				

ADV	Atole Tap 0	Atole Tap 1	Total	Cumulative Incidence
0	115	35	150	0.23
1	26	8	34	0.24
Total	141	43	184	
Risk Ratio 1.01				
Pearson chi2 = 0.0006 Pr = 0.981				

Table 18 shows the contingency tables for each of the food items cooked with tap water. Households consuming beans cooked with tap water increased in 57% their risk of suffering arsenicosis. The chi-squared value is statistically significant and a positive and statistically significant correlation coefficient between consumption of beans cooked with tap water and suffering arsenicosis was found. The rest of the estimations were not statistically significant. Finally, it was found that reporting arsenicosis symptoms is positively correlated with the litres of water used for cooking ($r=0.161$ $p=0.034$).

5.8 Discussion on the Exploratory Study

After analysing the wealth of data collected for the exploratory study, it was possible to answer the research questions posed during the first stage of the research. First, ***As*** and $\boldsymbol{F^-}$ groundwater contamination was confirmed. Two of the extraction wells from the system that provides water to the region have a ***As*** levels 10 and 16 times above the Mexican guideline. The $\boldsymbol{F^-}$ levels were two times above the guideline. On the other hand, all the tap water samples but one had concentrations of ***As*** and $\boldsymbol{F^-}$ above Mexican guideline. In relation to the first research question, it was found that the population is not aware of the ***As*** and $\boldsymbol{F^-}$ contamination problem. Less than 10 percent of the respondents know what are the health problems associated with fluoride and arsenic water contamination and very few were able to identify the symptoms before the interview. It was found that 41% of the households suffer fluorosis symptoms and 18% suffer arsenicosis symptoms. However, no ***As*** or $\boldsymbol{F^-}$ removal technologies are used at household level. Bottled water is the most important source of drinking water (57% of the interviewed households consume it) and Tap water is the most important source of cooking water (48% of the households cook with tap water). Some households use water filters. Nevertheless, the technologies available in the market are mainly designed for bacteria removal. The analysis of food and water consumption patterns revealed that cooking with tap water has important health implications. Cooking with tap water is the single most important risk factor for having at least a household member with fluorosis or arsenicosis symptoms. There is also a positive correlation between the litres of water used for cooking and suffering fluorosis and arsenicosis symptoms. The analysis in the exploratory study produced very useful information that was used in the second and third stages of this research. Nevertheless, due to the limitations of the survey data to disentangle a lot of the potential determinants of health outcomes it is necessary to conduct a more detailed epidemiological study in the future. Arsenicosis epidemiological studies usually collect samples of human tissues (nails and/or hair), blood or urine. Then, the concentrations of arsenic are determined in the laboratory and the results are crossed with information about arsenic levels in food and drinking water as well as consumption patterns (see for example Mazumder et al (2001, 2009 and 2014), Saha (2003), Ng et al (2003), Guha (2003), Kales and Christiani (2005), Khan et al (2005), Sampson et al (2008), Maden et al (2011), Paul et al (2013), Hashim et al (2013), Phan and Hashim (2014), Stea et al (2014), etc.). In the case of fluorosis epidemiological studies, fluoride levels are measured in urine and the Dean's fluorosis index (the standard classification of mottled enamel diagnosis developed by Dean (1934 and 1942)) usually used to classify the level of dental fluorosis in individuals (see for example Beltrán-Aguilar et al (2002 and 2010), Whelton (2004), Soto-Rojas et al (2004), Vallejos-Sánchez (2006), Medina-Solis et al (2008), Allibone et al (2012), Sarvaiya et al (2012), etc.). Then the results are crossed with information of fluoride intake. More in depth epidemiological studies are without doubt required. On the other hand, the local water authorities are aware of the contamination problem. They mix water from highly contaminated wells with water from others less contaminated as a method to reduce the levels of ***As*** and $\boldsymbol{F^-}$ in the water supply. No other technology for ***As*** and $\boldsymbol{F^-}$ removal is employed. Given the concentration levels of ***As*** and $\boldsymbol{F^-}$ found in the water samples collected, it is evident that this method is not satisfactory. It is recommended to assess the viability of the installation of a filtration system to remove fluoride and heavy metals in the region.

6. Contingent Valuation of Safe Groundwater in the city of Guadalupe.

In view of the results of the exploratory study, it was decided to conduct a contingent valuation of safe groundwater supply. Section 5.2 explains that Guadalupe depends heavily on its aquifers for the supply of its domestic water. There is evidence that the current pattern of exploitation is affecting the water quantity (groundwater extraction is higher than the average annual recharge) and the water quality (the F^- levels in wells 14 and 16 increased between 2002 and 2008) in the region. Therefore, groundwater protection must be a priority. In order to ensure the quality of the groundwater over time, it is necessary to develop a filtration system to remove fluoride and heavy metals.

The contingent valuation (CV) method is a survey-based technique that elicits stated preference behaviour, like willingness to pay (WTP), for changes in the provision of publicly provided or non-marketed goods (e.g. drinking water supply) (Mitchell and Carson 1989, Bateman et al 2002). Different elicitation questions (open-ended, iterative bidding, payment card, close-ended, etc.) are used to derive the WTP amounts. Since these values are contingent on the hypothetical market the method is called CV method (Carson and Groves 2007). The CV method has been used extensively to elicit WTP for water services in developing countries. In the specific case of Mexico, Ojeda et al (2008) conducted a contingent valuation survey in Ciudad Obregon, Sonora. This is the most populated city located in the water-scarce Yaqui River Delta in North West Mexico. Their aim was to estimate non-market values of the river's instream uses. Respondents were given a current and hypothetical Delta scenario (the latter assuming restored water flows in the Yaqui River). Then, they were asked a WTP question regarding purchasing water for environmental flows through higher water bills. Their results show that households are willing to pay an average of MXN 73 monthly for restored water flows. Soto and Bateman (2006) used two contingent valuation surveys to elicit WTP for two levels of water service quality: maintenance or improvement of water provision levels. They noted that higher-income households enjoy better levels of water provision. In contrast, poorer households endure lower standards of water supply. An interesting result of their research shows that richer households enjoying better water services showed higher WTP for programs to maintain the status quo but lower WTP for improvements. On the other hand, poorer households showed higher WTP for programs to improve the quality of water supply. Finally, they used an equity reweighting formula to equalize the income constraint across society. With this adjustment, the improvement scheme favored by poorer households yields higher net benefits. Their CBA estimation found that the benefits of either scheme were enough to cover the costs of implementation. Paniagua et al (2007) elicited WTP for water services in Tapalpa watershed in Jalisco, Mexico. They used a CV survey that administered to stakeholders in different sectors. They found an average WTP for water services of USD 9.10. Vazquez et al (2009) elicited household WTP for safe and reliable drinking water in Parral, Chihuahua (Northern Mexico). They used a referendum-format CV survey. The respondents in their study considered that their water system is quite good. However, they also found that households spend a considerable amount of their disposable income on averting risks related to the quality and reliability of the existing water supply system. Further, they found that the respondents are willing to pay up to 7.55% of their reported household income on top of their current water bill for safe and reliable drinking water services. Avilés-Polanco et al (2010) estimated households WTP to maintain water supply from “La Paz” aquifer in Baja California Sur, Mexico. The results from their CV survey show that the households have an average WTP of USD 10.5 for maintaining the aquifer’s water supply. They also found that households with higher water consumption have lower WTP to maintain water supply from the aquifer (because higher consumption increases the total amount they would have to pay for water). In addition, households that have an irregular access to water have a higher WTP, compared with those with continuous flow of water. The results of these studies have been used in a number of public policies aimed to provide improved water services (for example, CBA, setting price rates, etc.).

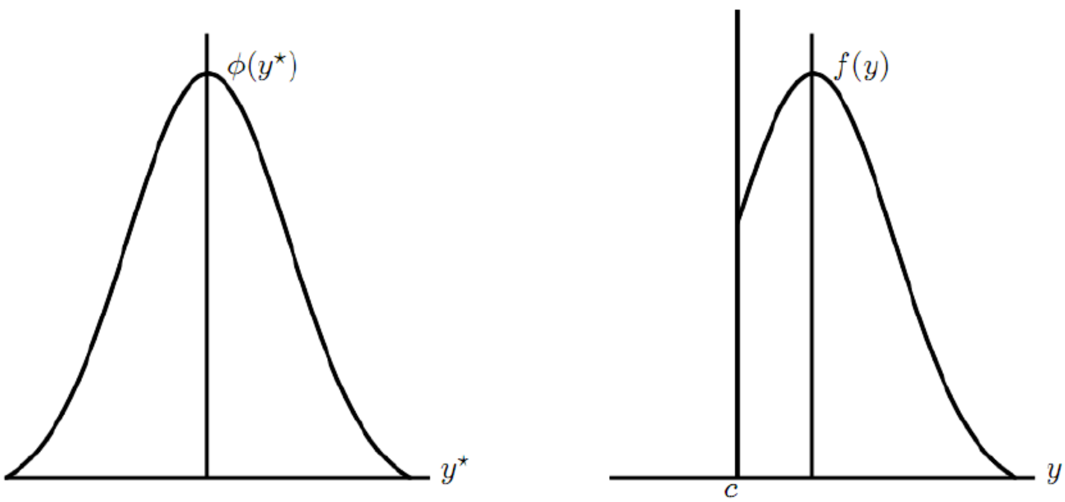
6.1 Theoretical Framework and modelling approach

This section provides a utility-theoretic framework for consumer responses to improvements in water quality and system reliability. Suppose that $v(y, w, p, z)$ is the indirect utility function of a household that increases with income (*y*) and positive attributes of water services (*w*). Vector *w* contains different attributes (for example, quality and reliability of tap water provision) relevant to the provision of water services. Indirect utility *v*, decreases with prices of other goods (*p*), and is also affected by the household’s features (*z*). Hence, the household will be willing to pay for water service improvements up to the extent that this payment does not decrease their utility below the original utility level. Thus, a Hicksian surplus (the household maximum willingness to pay (WTP) for any improvement in water services for example the installation of a new filtration system to remove fluoride and arsenic from groundwater) is defined as:

1) $v(y, p, w_0, z) = v(y - wtp_1, p, w_1, z) = v(y - wtp_2, p, w_2, z)$

where, (w_0) represents the current provision of water services, (w_1) represents improved quality of drinking water under the proposed project (i.e., the increment in only water quality), and (w_2) represents some separate additional improvement in water services, such as system reliability. A household's WTP for water services is a function of these multidimensional water attributes: income, prices of other goods, and other relevant household characteristics. Given that (w_1) and (w_2) represent separate improvements, then *wtp* for the combined improvement ($w_1 + w_2$) (i.e., wtp_{1+2}) would be greater than the WTP for the water quality improvement alone (w_1) (i.e., $wtp_{1+2} > wtp_1$). Following Carson and Mitchel (1995), this provides a test of scope for a nested good. In the contingent valuation literature, Ordinary Least Squares (OLS) regressions are commonly used to estimate a WTP model from responses to an open-ended question. However, if the sample is censored it is not appropriate to use OLS. A censored value can be defined as follows. Let y^* be a normally distributed variable with mean μ and variance σ^2. An observed variable is censored below if: $y = c$ if $y^* \leq c$ and $y = y^*$ otherwise. In this case, c is a given constant (see figure 5).

Figure 5 Normal Variable y* and Censored variable y



If a number of WTP observations have a zero value, the sample could be censored and OLS is not an appropriate model to use. In addition, it is necessary to differentiate between true zero bids and protest zeros. True zero bids reflect the respondent's true preferences. According to Strazzera et al. (2003), zero is the reservation price for respondents that are indifferent to the increase in the provision of the public good. In contrast, protest zeros reflect an objection towards a component of the survey design (e.g. payment vehicle) or ethical objections to payment for a public good (Bowker et al. 2003). Protest zero bids may be high when controversial policies are proposed. In order to model WTP with zero and protest bids a Tobit model with binary selection (TBS) is used. In this model, WTP responses are categorised into protest and not protest as a binary probit model. A binary sample selection rule identifies protest zero bids and a censored Tobit mechanism is used to adjust true zero bids among non-protesters. The respondent's preference results from a joint process that involves the choice to reveal and the choice to value. First, the binary sample selection models the choice to reveal. Then, the censored Tobit is used to model the choice to value the WTP including true zero WTP. This model treats WTP (y) as a censored dependent variable subject to a binary sample selection rule to adjust a protest outcome (w = 0). The model is characterised as:

$$\text{3)} \quad \begin{aligned} w &= 1 \; if \; z'\alpha + u > 0 \\ &= 0 \; if \; z'\alpha + u \leq 0 \end{aligned}$$

and

$$\text{4)} \quad \begin{aligned} y &= 0 & & if \; z'\alpha + u > 0 \;\; and \\ & & & x'\beta + v \leq 0 \\ &= x'\beta + u \leq 0 & & if \; z'\alpha + u > 0 \;\; and \\ & & & x'\beta + v \leq 0 \\ &= unobserved & & if \; z'\alpha + u \leq 0 \end{aligned}$$

In Equations (3) and (4), z and x are vectors of explanatory variables, α and β are conformable parameter vectors. It is assumed that the error terms u and v have a bivariate normal distribution with mean zero and a finite covariance matrix:

$$\text{5)} \; \begin{bmatrix} u \\ v \end{bmatrix} \sim N\left(0, \begin{bmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{bmatrix}\right)$$

where σ is the standard deviation of u_2 and ρ is the correlation between u_1 and u_2. In this model, WTP (y) can be zero (censored) or positive when protest does not occur (w=1) and is treated as unobserved when protest occurs (w=0). Then the sample likelihood function is:

$$6)\ L = \prod_{w=0}[1 - \Phi(z'\alpha)] \times \prod_{w=1,y=0} \Psi[z'\alpha, -\frac{x'\beta}{\sigma}; -\rho]$$
$$\times \prod_{w=1,y>0} \frac{1}{\sigma}\phi\left(\frac{y - x'\beta}{\sigma}\right) \times \Phi\left(\frac{z'\alpha + \rho(y - x'\beta)/\sigma}{(1-\rho^2)^{1/2}}\right)$$

where ϕ (.) is the univariate standard normal probability density function (pdf) and Φ (.) is the cumulative distribution function (cdf), respectively. In addition, Ψ $(\cdot,\cdot,\rho)$ denotes the standard bivariate normal cdf with correlation ρ. The three components of the likelihood function represent, respectively, the probability of protest (w=0), no protest but censored (w=1, y=0), and the conditional density of WTP (y) conditional on no protest and no censoring (w=1, y > 0). The likelihood function in equation 6 allows the ML estimation of the model presented in the following section. A follow up question for individuals bidding zero WTP asked the reason for objecting. The answers included: a) I cannot afford paying more, b) There have been water supply interruptions in my neighbourhood and c) I am leaving the community. Households answering a) and c) were considered true zero bidders. Households answering b) were classified as protests. Table 19 shows the frequency and percentage in each response category.

Table 19. Frequency and Percentage in each Response Category

Responses	Freq.	Percentage
Protest	36	12.00
True zero	19	6.33
Positive	244	81.33
Missing	1	0.33
Total	300	100.00

6.2 Data collection mode and sample size

A contingent valuation survey was used to elicit willingness to pay responses for the installation of a water filtration system in Guadalupe (see Appendix 3). The collection of primary data was done through personal interviews conducted face to face. Provision of information on the item being valued is a fundamental component of a contingent valuation survey. Personal interviews have the highest ability because visual information is provided and the interviewer is available to explain the information and answer questions. Guadalupe city is the capital of Guadalupe municipality. According to 2010 census, it has 124,623 inhabitants (INEGI 2010). Considering margin of error of 8% and a 95% confidence level, the required sample size[g] was 150 questionnaires. It was decided to conduct 300 questionnaires in total to allow the identification of 2 subsamples of 150 questionnaires each. A stratified random sampling strategy was used to select the households to be interviewed. The survey was pretested and implemented in June 2011 and February 2012. The researcher conducted face to face interviews aided by a Mexican research assistant educated at postgraduate level who had previous experience in other research projects. Training on identification of fluorosis and arsenicosis symptoms was also provided.

6.3 Design of the information component of the survey instrument

The survey instrument consists of six sections. The first section records the time and place of the interview and the number of years that the respondent has lived in the municipality. Only respondents living in Guadalupe city were interviewed. The second section records socio-demographic characteristics of the household. In the third section, respondents are asked to evaluate the current water system. Respondents were asked to rate the current tap water quality on a five-point scale, with 1 being "very poor" quality and 5 being "very good" based on taste, odour, and colour. A *quality* variable was estimated by obtaining the average value of these three quality characteristics. In the fourth section, respondents report on their consumption of substitute goods (bottled water and filtered water). Here is also asked to respondents to specify the main reasons for purchasing bottled water or using a water treatment device. Three options were offered: Taste, health concerns and other reasons. In all 3 cases it is required that the respondent elaborate on her answer. In the fifth section, sampled households report their expenditures on food and both tap and bottled water. The sixth section includes the valuation component of the survey and a follow up question. After presenting the contingent scenario, each respondent

[g] The sample size formula used here is the same as that used in section 5.

was presented with an open-ended valuation question. From the exploratory study and the research presented in Annex 1, it was found that the tap water is contaminated with Fluoride and Arsenic. Thus, the base good valued presented to all respondents is the provision of drinking water free of fluoride or free of arsenic at the tap through the installation of a new filtration system in the municipality. Individuals' subjective perceptions of contamination (by fluoride or arsenic in this case) may change their behaviour in that the households purchase in-house water purification systems or bottled water thereby changing the effective price of potable groundwater. The experimental design included a four split-sample treatment (2x2), with variations in the reliability and quality of provision for implementing the good. Two different types of provision were randomly assigned to the split samples: a) Reliable water provision (24/7) or the current unreliable water provision b) Complete or partial arsenicosis symptoms reduction (following the WHO/MON guidelines) and/or complete or incomplete fluorosis symptoms reduction (0 or under the MON 1.5 mg/L guideline). Sampled households were randomly assigned one of the four treatments. Since the split-sample treatment allows the valuation of an improvement in water quality or the valuation of an improvement in water quality and system reliability, then this is a test of scope of a nested good (Carson and Mitchell, 1995). In the valuation section, the characteristics of the existing water system are described and an improvement in the provision of drinking water is presented. It has variations in the reliability of the water supply and the quality of provision across respondents according to the experimental design. The Inter-municipality Board of Drinking Water and Sewerage is the public institution in charge of the water management in Zacatecas. It was explained that the extra fee would be collected through the normal water fee receipt. Respondents were reminded that money spent on this additional fee will not be available for other household expenses. The WTP survey and graphic materials are included in the Appendix 3

6.5 Profile of the respondents

Tables 20 and 21 show the interviewees' characteristics. The respondents' average age is thirty-eight years. The average age is consistent with the survey design because normally mature people are responsible for the household administration. On average the interviewees reported that they have lived in the municipality for 23 years. This information was very relevant in order to understand the reasons for protest, as it will be explained later. The average number of household members is 4.33 and at least one household member is a child under 14. The average monthly household income is 5,156.81 Mexican Pesos. The average monthly expenditure in food is 2,580.47 Mexican Pesos. The previous figures suggest that an average household use 50% of its income in food consumption. 56% of the respondents are female. 16% of the respondents stated that in their households they drink tap water. However, 44% of the respondents stated that they use tap water for cooking. These figures are consistent with the responses obtained during the exploratory study. 84% of the respondents stated that in their households they purchase bottled water. This is evidence of averting behaviour. In Mexico, the standard water bottle aimed for household consumption has a capacity of 20 litres. An average household consumes more than 2 bottles of water per week and spends around 47 Mexican Pesos monthly in the bottled water purchases. Bockstael and McConnell (1999), report that a number of studies (e.g. Abdalla et al., 1992 and Wu and Huang, 2001) compare CV estimates and averting expenditures related to water quality (e.g. bottled water expenditure) and conclude that averting expenditure can be a lower bound to WTP. The average monthly expenditure on tap water is 128 Mexican Pesos per household. There is in place a metering system for tap water consumption. A positive and statistically significant correlation coefficient between the number of household members and tap water expenditure was found (r=0.172 p=0.0029). The differences with the figures obtained in the exploratory study are explained by the differences in tap water fees and bottled water consumption patterns in both municipalities.

Table 20 Average profile of a sample respondent (a)

Description	As		F		All	
	Mean	SD	Mean	SD	Mean	SD
Age of the respondents	37.90	13.52	37.29	13.79	37.60	13.66
Years living in the municipality	22.51	15.37	22.69	16.32	22.60	15.85
Household members	4.21	2.02	4.45	1.88	4.33	1.95
Children under 14	1.26	1.24	1.07	1.14	1.16	1.19
Household Income	5160.00	3738.30	5153.62	3454.86	5156.81	3596.58
Expenditure in food	2624.33	1729.11	2536.60	1538.11	2580.47	1633.61

Table 21 Average profile of a sample respondent (b)

Description	As	F	All
Percentage of female respondents	51	61	56
Percentage of households who drink tap water.	18	14	16
Percentage of households who cook with tap water.	40	47	43.5
Percentage of households who purchase bottled water	82	86	84
Average number of bottles of water consumed per week	2.53	2.79	2.66
Monthly expenditure on bottled water	44.68	49.49	47.085
Monthly expenditure on tap water	121.20	134.28	127.74

6.5 Explanatory variables and expected signs

Table 22 presents the definitions and descriptive statistics of the variables used in the regression analysis. Not protest (NotProt) is a response dummy variable. It takes the value of 1 if there is a not protest response and 0 otherwise. Seven explanatory variables were considered. First, it was included the perceived tap water quality (Quality). It is considered that respondents who perceive a better tap water quality are less likely to protest and object the project. Specific personal characteristics like gender (Sex) and age (Age) and education (Education) are included. Food expenditure (FoodExp) is used as a proxy for household income. Other alternatives like measurement of wealth via assets was not considered because the respondents in Mexico are very reluctant disclose information about their assets or income. The reason is that kidnapping and burglary are crimes prevalent in the region. Food expenditure was considered a better alternative. Halstead et al (1992) report that there is some evidence that respondents with higher education levels, age, and income are less likely to register protest zero bids however, some other studies have found opposite results. Therefore, the expected sign of these variables remains ambiguous before the estimation of coefficients. The number of years living in the municipality (YearsMun) was included in the selection equation because respondents that have lived for longer in Guadalupe are more aware of the local problems and needs (specially in relation to the water provision services). Some of the respondents protesting for the lack of water provision in their neighbourhood also mentioned some other infrastructure projects that were never completed in the past. Therefore, it is expected a negative effect on the “not protest” variable. The household members (HouseMem) variable was included. The lack of water supply in households with more family members may trigger more protests. Finally, the variable for children (Children) under 14 in the household was also included. If altruistic behaviour is present, then the having children in the household may not protest and oppose the project.

For the WTP equation, 9 explanatory variables were included. The response variable of the equation is willingness to pay for the project (WTP). Respondent specific variables such as gender, age, education and food expenditure were included. The number of household members and the number of children in the household was also included. It can be expected that households with more household members (HouseMem) are less willing to pay for the project since because of their budget constraint. The perceived quality of the tap water was also included. It can be expected that households with better perceived water tap quality would be less willing to pay for the project since they may perceive a smaller improvement from the current water supply system. Households with higher bottled water expenditure (BWX) are expected to report a higher WTP because the proposed improvement in the water system would be expected to provide a less expensive substitute for bottled water. However, this variable was excluded from the final model. In a preliminary analysis, it was found that BWX is negatively correlated with the perceived water tap quality ($r= -0.1024$ $p=0.091$) (i.e. households with a better perception of tap water quality would spend less money on bottled water) and it had a variance inflation factor (VIF) of 8.1. A multicollinearity problem could be a concern because it can inflate the variance of parameter estimates and limit the accuracy of estimation (Cho et al 2008). Nevertheless, the VIFs of the rest of explanatory variables are all lower than 3.5. The dummy variable Reliable is used to estimate the effect of the change in the scope of water system services, through the absence or presence of water service reliability. The variable symptoms reduction (SymptomsRed) dummy variable estimates the change in the scope of water system services, through the reduction of fluorosis or arsenicosis symptoms. It is expected that households are more willing to pay if reliability and complete symptoms reduction are offered. The expected signs of the coefficients of the explanatory variables on WTP are also included in Table 22.

Table 22 Variables definition and descriptive statistics (n = 300)

Variable	Definition	Mean	SD	Expected Sign	
				Selection Eq.	WTP Eq.
Age	Age of respondent (in years)	37.597	13.636	+/-	+/-
Children	Number of children under 14	1.164	1.191	+/-	+/-
Education	Respondent's education (in years of schooling)	2.890	1.573	+/-	+/-
FoodExp	Monthly expenditure in food in MXN	2.555	1.647	+	+
HouseMem	Number of Household members	4.433	1.950	-	-
Quality	Average Subjective perception of the tap water quality on a 5 point scale (1=very bad, 2= bad, 3=regular, 4= good, 5=very good)	2.852	0.984	+	-
NotProt	Response dummy variable. Takes the value of 1 if there is no protest and 0 otherwise.	0.880	0.320		
Sex	Gender of the respondent: Female=1, Male=0	0.565	0.497	+/-	+/-
YearsMun	Number of years Living in the municipality	22.604	15.826	+	Not included
Reliable	Dummy variable that takes the value of 1 if system reliability is offered and 0 otherwise	0.497	0.501	Not included	+
SymptomsRed	Dummy variable that takes the value of 1 if complete symptoms reduction are offered (WHO guideline) and 0 otherwise (partial reduction under the MON guideline)	0.477	0.500	Not included	+
WTP	Willingness to pay for the project (Fluoride)	56.550	77.517		
	Willingness to pay for the project (Arsenic)	66.371	81.340		

Table 23 presents ML estimates of the TBS for two models: Fluoride and Arsenic. The selection equations are analysed first. The estimated coefficients for the selection equation show that in both models the number of years living in the municipality has a negative and statistically significant effect on the not protest (NotProt) explanatory variable. That is, people living for longer in the municipality are more likely to protest. In the Fluoride model, the age of the respondent also has a negative and statistically significant effect on NotProt. Older people are more likely to protest. In contrast, a positive and statistically significant coefficient was found for the quality of tap water variable. Households with a perceived better quality of tap water are less likely to protest. For the Arsenic model, the positive and statistically significant coefficients for Education and Children mean that more educated people and households with children under 14 are less likely to protest. The rest of the explanatory variables in the selection equations are not statistically significant.

Now, the WTP coefficients are analysed. In the Fluoride model, there is a negative and statistically significant coefficient for the number of household members as expected. On the other hand, the positive and statistically significant coefficients found indicate that respondents with more schooling years and with children in the household are more willing to pay for the project (there is evidence of altruistic behaviour). Respondents are more willing to pay if a reliable water supply system is proposed and if a full reduction of fluorosis symptoms is offered. In the Arsenic model, men are more willing to pay for the project. Also, the level of education of the respondent and the presence of children in the household has a positive and statistically significant effect on the WTP. Finally, respondents are more willing to pay if a reliable water supply system is offered. The sign of the coefficient for a full reduction of arsenicosis symptoms is positive as expected and the sign of the coefficient of tap water quality perception is negative as expected. However, they are not statistically significant. The rest of the explanatory variables were not statistically significant either.

Table 23 Maximum-Likelihood Estimates: Tobit Model with Sample Selection

Variable	Fluoride	Arsenic
WTP		
Sex	-17.3163	-30.3791**
Age	-0.5583	-0.2759
Education	8.5496*	10.5908**
HouseMembers	-10.0758**	-5.6693
Children	11.2484*	19.1419***
SymptomsRed	16.9822***	17.7295
Reliable	11.6722***	7.3773***
Quality	-8.7739	-0.0663
FoodExp	5.6735	-0.2635
_cons	84.4384*	53.3189
Binary Probit Selection: NotProt		
YearsMun	-0.0056***	-0.0100***
Sex	-0.1484	-0.0261
Age	-0.0168**	-0.0002
Education	0.0152	0.1087*
Children	0.0775	0.2913***
HouseMembers	-0.0585	-0.1029
Quality	0.2142**	0.0971
FoodExp	0.0247	-0.0438
_cons	1.0329*	0.7692
rho	17.8249	16.0659
sigma	4.3798***	4.3826***
Statistics		
N	148	148
ll	-7.59E+02	-7.85E+02
df_m	9	9
chi2	2.24E+06	3.26E+06

Legend: * p<.1; ** p<.05; *** p<.01

At the sample mean of relevant explanatory variables, the expected value of the unconditional WTP for the Fluoride model is MXN 51.88 on top of the household monthly water bill. The average household expenditure on tap water fees is MXN 127.74. The estimated WTP figure corresponds to an increase of 40.61% above the current average tap water expenditure and corresponds to 2.01% of the proxy for household income (FoodExp). The addition of the current tap water expenditure and the predicted WTP corresponds to 6.95% of the proxy for household income. The predicted WTP is MXN 66.44 if a reliable water supply system is offered along with a reduction of fluorosis symptoms in line with the WHO guidelines. The predicted WTP is MXN 54.77 if an unreliable system along with a reduction of fluorosis symptoms in line with the WHO guidelines is offered. If a reliable water supply system is offered along with a reduction of fluorosis symptoms in line with the MON guidelines the predicted WTP is MXN 49.46. Finally, the predicted WTP is MXN

37.79 if an unreliable system along with a reduction of fluorosis symptoms in line with the WHO guidelines is offered. The results show evidence of sensitivity to scope for a nested good. In all cases the predicted WTP for combined improvements in water quality (in terms of fluoride and arsenic symptoms reduction) and reliability of water supply exceeds the WTP for improved water quality or reliability alone.

On the other hand, the predicted unconditional WTP for the Arsenic model is MXN 61.79 on top of the household monthly water bill. The estimated WTP figure corresponds to an increase of 49.37% above the current average tap water expenditure and corresponds to 2.39% of the proxy for household income. The addition of the current tap water expenditure and the predicted WTP corresponds to 7.34% of the proxy for household income. A predicted WTP of MXN 65.33 is found if a reliable system is offered. In addition, the predicted WTP is MXN 57.95 if the current reliability levels are maintained. In this case, there is also evidence of sensitivity to scope for a nested good. The WTP for a reliable water supply system is higher than the WTP for an unreliable system. Table 24 shows a comparison of the predicted WTP estimates.

Table 24 Comparison of Predicted WTP Estimates

	Predicted WTP	[95% Conf.	Interval]	WTP increase in relation to current tap water expenditure (%)	WTP in relation to household income (FoodExp) (%)	WTP + current tap water expenditure in relation to FoodExp (%)
Fluoride						
Unconditional	51.88	38.59	65.17	40.61	2.01	6.96
Reliable =1 SymptomsRed=1	66.44	53.15	79.73	52.01	2.57	7.52
Reliable =0 SymptomsRed=1	54.77	41.48	68.06	42.87	2.12	7.07
Reliable =1 SymptomsRed=0	49.46	36.17	62.75	38.72	1.92	6.87
Reliable =0 SymptomsRed=0	37.79	24.49	51.08	29.58	1.46	6.41
Arsenic						
Unconditional	61.79	48.28	75.31	48.37	2.39	7.34
Reliable=1	65.33	51.55	79.11	51.14	2.53	7.48
Reliable=0	57.95	44.27	71.64	45.37	2.25	7.20

6.5 Discussion

The exploratory and contingent valuation studies show that households in Guadalupe conduct private investment and different averting activities in order to deal with interrupted water supply and the (partial) perception of poor quality tap water. The results show a significant household WTP for improved water services because in general the households consider that the current water system is unreliable. The exploratory study found that households' investment in private infrastructure in order to have uninterrupted access to tap water (23% of the households in the sample have a water cistern and 89% have water tanks). Bottled water is also commonly purchased for drinking and cooking purposes (75% of the households consume bottled water), and a number of other household based activities are applied to treat tap water (mainly boiling water or using water filters). It is evident from these practices that there is a demand for more reliable and better quality water services in Guadalupe. It was found that the average tap water fee is MXN 128. The results also indicate that the households have an average unconditional WTP of MXN 51.88 in the Fluoride and MXN 61.79 for the Arsenic. This is equivalent to an increase of 40% and 48% above the average water fee respectively. Combined with current tap water expenditures, this increase in monthly water bills is equivalent to 2.0% and 2.3% of the reported average income. Table 25 presents a comparison between different CV studies conducted in Mexico. Only those concerned with drinking water with were considered. There are evident variations at country level. Soto and Bateman (2006) found the highest WTP for drinking water services was in Mexico City. Gutierrez-Villalpando (2006) found the lowest WTP in Chiapas. The average WTP results for the Arsenic model in this study would be located in the middle range of the values presented in the table. The WTP value estimated by Vasquez et al. (2009) is quite relevant since the water supply in Chihuahua is quite unreliable and is also contaminated. There is a difference of about 2 USD between his estimate and the mean WTP estimated for the Arsenic model. The difference could be explained because Chihuahua's wages (and in general in northern Mexico) are usually higher than in the rest of the republic due to its proximity with the border with the US and the economic activities more industry oriented.

Table 25 Comparative Contingent Valuation Studies for Drinking Water in Mexico

Authors	Study Site	Service	Method	Adjusted WTP (US$ / Month)[a]
Soto Montes de Oca and Bateman (2006)	Mexico City	Water Supply Change	Contingent Valuation	15.81
Vasquez et al. (2009)	Parral, Chihuahua	Drinking Water	Contingent Valuation	8.91
Gutierrez-Villalpando (2006)	San Cristobal de las Casas, Chiapas	Drinking Water and Wildlife Habitat	Contingent Valuation	1.82
Paniagua et al (2007)	Tapalpa, Jalisco	Drinking Water	Contingent Valuation	9.10
Aviles-Polanco, et al. (2010)	La Paz, BCS	Drinking Water	Contingent Valuation	10.15
This study (Arsenic model WTP)	Guadalupe, Zacatecas	Drinking Water	Contingent Valuation	5.93

[a] Based on Februrary-2011 price levels (USD1 = MXN13) and 10-year average of the National Consumer Price Index =4.03%)
Source: Adapted from Perez Verdin et al (2012) with the author's calculations

According the National Institute of Statistics (INEGI 2010) the number of inhabited households in Guadalupe is 41,783. Therefore, the monthly municipal revenue for a fee increase of MXN 61 (the arsenic average unconditional WTP) would be MXN 2,548,763. An arsenic filtration system constructed in 2011 in Zimapán Hidalgo required an investment of MXN 28,000,000 (CONAGUA 2011). It is considered that the required funding for the installation and operation of the filtration system similar to the one operating in Hidalgo could be achieved in less than a year given the estimated WTP for Arsenic. However, more research is required in order to identify the most appropriate technology and alternatives of funding for the municipality of Guadalupe. The local water authorities can use the estimated CV results presented in this section in order to inform a cost-benefit analysis. In addition, a very detailed analysis of the economic uses of water resources in Guadalupe is highly recommended. It should be kept in mind that increasing the water fees is not a straight-forward solution. During the fieldwork several respondents complained about the frequent and long water supply cuts and argued that they are not willing to pay for a service that is not provided. In our sample, 12% of the respondents objected the project. In addition, the water treatment plant can solve the contamination problem but not the scarcity problem. Alternatives should be sought in order to find solutions for this pressing issue.

Conclusions

The very fact that Zacatecas is located at high altitude (2,420 metres above sea level) increases the risk of fluorosis among its population. There is overwhelming evidence about the high prevalence and severity of fluorosis in communities located at 1,500 m above sea level (see for example Manji et al 1986, Mabelya et al 1992, Irigoyen et al 1995, Angmar-Mansson and Whitford 1990, Molina *et al* 1999, Cao *et al* 2003, Soto Rojas *et al* 2004, Pontigo-Loyola et al 2008, Akosu et al 2009, Ramadan and Hilmi 2014, etc.). Therefore, efforts should be done for a modification of the F^- 1.5 mg/l guideline value in the Mexican Official Norm. However this is not enough. There is a serious problem of enforcement and monitoring of environmental and sanitary laws and norms (for example the enforcement of the Mexican Official Norm NOM-040-SSA1-1993 that prohibits the distribution of fluoridated salt). There is also a severe information problem. The population is not aware of the high levels of ***As*** and F^- in the tap water and the majority has no information concerning arsenicosis or fluorosis symptoms and the strategies to avoid them. Data about toxic elements levels in the public water systems and the environment are not available to the public despite the fact that the General Law for Prevention and Integral Waste Management (SEMARNAT 2003) established the right to information and created the National Information System for Integral Waste Management. This information system should contain information about the local environmental situation, waste stock, the infrastructure available for its management, bylaws and other laws relevant for waste regulation and control. However, a quick search in the on-line databases of this National Information System informs that between 2004 and 2011 the mining industry produced 0.00 Tons of hazardous waste.[h] However, hazardous waste from the mining industry is accumulating in agricultural areas of Guadalupe and Arsenic and heavy metals could enter the food chain and contaminate the aquifers (see Annexes 1 and 2). On the other hand, households in Guadalupe conduct private

[h] This information is available in the following link:
http://dgeiawf.semarnat.gob.mx:8080/ibi_apps/WFServlet?IBIF_ex=D3_RESIDUOP01_22&IBIC_user=dgeia_mce&IBIC_pass=dgeia_mce

investment and different averting activities in order to deal with interrupted water supply and the (partial) perception of poor quality tap water. The CV study shows that there is a demand for reliable and good quality water services in Guadalupe. The results of this research show that the installation and operation of a water treatment plant in the region is of primary importance. Therefore, different sources and schemes of funding should be analysed and considered. Nevertheless, it must be mentioned that higher water fees are not a definitive solution. A water treatment plant can solve the contamination problem but not the scarcity problem. During the fieldwork several respondents complained about the frequent and long water supply cuts. The over-exploitation of the aquifers will pose a real constraint for water supply in the near future. Negative health impacts due to the consumption of contaminated water could also be expected. An in-depth analysis of the economic uses of water resources is highly recommended. Finally, the number of people affected with fluorosis and arsenicosis in the study area could be higher than the already detected. There is evidence that the fluoride concentration levels in the local water wells are increasing over time (see section 5). On the other hand, people living in severely contaminated zones are at higher risk (see Annex 1 and 2). Therefore, there is an urgent need of conducting more environmental, epidemiological and socio-economic studies in the area. Arsenic and fluoride must be determined in all groundwater sources in Zacatecas and Guadalupe municipalities on a regular basis. A comprehensive public strategy to tackle the problem is required.

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Appendix 1 Exploratory Study Survey

Folio:

Tap Water Contamination in Zacatecas, Mexico: an Exploratory Study / Contaminación de agua de la llave en Zacatecas, México: Estudio Exploratorio

Researcher/Investigador: Osiel González Dávila

Enumerator/Encuestador:

	Day/Día	Month/Mes	Year/Año
1. Date/ Fecha		October	2010

2. Municipality/ Municipio	Guadalupe	Zacatecas
3. Address / Dirección		

4. For how long have you lived in the municipality?/ ¿Por cuántos años ha vivido en el municipio?	Years/Años	

7. Marital Status/ Estado Civil	

5. Sex/ Sexo	F	M

6. Age/ Edad	Years/Años	

8. Number of household memebers/ Número de personas que habitan en su casa		9. Number of children under 14/ Número de niños menores de 14 años	

10. Education/ Educación	No Education/ Ninguna educación	Elementary/ Primaria	Secondary/ Secundaria	High school/ Preparatoria	Technical Ed./ Edu. Técnica	Higher Education/ Educación Superior	Postgraduate/ Postgrado
Complete or Incomplete/ Completa o Incompleta							

11. Main economic activity of the head household/ Principal actividad económica del jefe de familia				
12. Monthly household income/ Ingreso mensual del hogar				
13. Monthly expenditure in food/ Gasto mensual en alimentos				
14. Monthly expenditure in household water/ Gasto mensual en agua de la casa				
15. Monthly expenditure in bottled water/ Gasto mensual en agua embotellada				
16. Main Drinking Water Supply/ Principal fuente de agua para beber	Tap/ llave	Filter/ Filtro	Bottled/ Botella	Other/ Otra:
17. Main Cooking Water Supply/ Principal fuente de agua para cocinar	Tap/ llave	Filter/ Filtro	Bottled/ Botella	Other/ Otra:

18. Main Other Uses Water Supply/ Principal fuente de agua para otros usos	Tap/ llave	Filter/ Filtro	Bottled/ Botella	Other/ Otra:	
19. Water Filter Brand/ Marca de filtro de agua					
20. Have you noticed changes in your tap water (last 3 years)?/ ¿Ha notado cambios recientes en el agua de la llave (en los últimos 3 años?	No	Colour/ Color	Taste/ Sabor	Other/ Otro:	
21. Glasses of drinking water per day (250 ml) / Vasos de agua consumidos por día (250 ml)					
22. How many water litres do you use for cooking? ¿Cuántos litros de agua utiliza para cocinar?					
23. Do you have in your household?/ ¿Tiene usted en su hogar?	Cistern/ Cisterna	Water tank/ Tinaco	Barrels/ Tambos	Buckets/ Cubetas	

24. Do you know what is arsenic?/ ¿Conoce el arsénico?	Yes/Si		No	
25. Do you know the disease provoked by arsenic?/ ¿Conoce la enfermedad que provoca el arsénico?	Yes/Si		No	
26. Do you know the symptoms?/ ¿Conoce los sítnomas?	Yes/Si		No	
27. Are there cancer patients in your family?/ ¿Algún miembro de su familia padece cancer?	Yes/Si		No	
28. Relationship with you/ Relación con usted				
29. Gender and number/ Género y número	M		F	
30. Are there cancer patients in your neighbourhood?/ ¿Alguien en su vecindario padece cancer?	Yes/Si		No	
31. Gender and number/ Género y número	M		F	
32. Do you have health services?/ ¿Cuenta con servicios de salud?	Yes/Si		No	
33. Health service name/ Nombre del servicio de salud				

34. Do you or a household member exhibit brown mottling of teeth? (see picture F1) / ¿Usted o alguien en su casa presenta manchas cafés en los dientes? (ver foto F1)	Yes/ Si	No
35. Do you or a household member exhibit patchy pigmentation of the skin? (see pics A1 and A2) / ¿Usted o alguien en su casa presenta manchas en las palmas de las manos? (ver fotos A1 y A2)	Yes/ Si	No

36. Food Consumption (times per week)					
Soup/ Sopa	Beens / Frijoles	Chicken soup / Caldo de pollo	Stew/ Guiso	Coffee/ Cafe	Atole

Picture F1 Dental fluorosis

Source: Report of the Forum on Fluoridation (2002:126)

Picture A1 Melanosis

Picture A2 Hyperkeratosis

Appendix 2 Complementary Salt Consumption Survey

Folio:

Salt and Water Consumption Survey in Zacatecas, Mexico (Complementary Survey) / Consumo de Sal y Agua en Zacatecas, México (Encuesta Complementaria)

Researcher/Investigador: Osiel González Dávila
Enumerator/Encuestador:

	Day/Día	Month/Mes	Year/Año
1. Date/ Fecha		June/Junio	2011

Municipality/Municipio	Guadalupe
2. Address / Dirección	

3. For how long have you lived in the municipality?/ ¿Por cuántos años ha vivido en el municipio?	Years/Años	

4. Sex/ Sexo	F	M

5. Age/ Edad	Years/Años	

6. Number of household memebers/ Número de personas que habitan en su casa	

7. Do you know what is fluorosis?/ ¿Sabe que es la fluorosis?	Yes/ Si	No	
8. Do you know what are the symptoms of fluorosis?/ ¿Sabe cuales son los sintomas?	Yes/ Si	No	
9. Do you know how to avoid fluorosis?/ ¿Sabe como evitar la fluorosis?	Yes/ Si	No	
10. Is the salt that you use for cooking fluoridated?/ ¿La sal con la que cocinan en su casa esta fluorada?	Yes/Si	No	Do not Know/ No Sabe
11. How many water glassess do you consume per day?/ ¿Cuantos vasos de agua toma al dia?			
12. How many soda glassess do you consume per day?/ ¿Cuantos vasos de refresco toma al dia?			
13. How many coffee glasses do you consume per day?/ ¿Cuantos vasos de café toma al dia?			
14. Number of days of milk consumption per week/ ¿Cuantos veces consumen leche a la semana en su casa?			
15. Number of days of stew consumption per week/¿Cuantas veces consume caldo de pollo o caldo de res a la semana?			
16. Mention other drinks consumed in your household /Mencione que otras bebidas consumen en su casa			
17. The water that you use for cooking is/El agua que usan para cocinar en su casa es...	Tap/ Llave	Bottle/ Botella	Filter/ Filtro
18. Do you or a household member exhibit brown mottling of teeth? (see picture F1) / ¿Usted o alguien en su casa presenta manchas cafés en los dientes? (ver foto F1)	Yes/Si	No	

Picture F1 Dental fluorosis

Source: Report of the Forum on Fluoridation (2002:126)

Appendix 3 Contingent Valuation Survey

Contingent Valuation for Safe Drinking Tap Water in the City of Guadalupe, Zacatecas-Mexico / Valuación Contingente de Agua de la Llave Segura para Beber en la Ciudad de Guadalupe, Zacatecas-México

Researcher/Investigador: Osiel González Dávila
Enumerator/Encuestador:

	Day/Día	Month/Mes	Year/Año
1. Date/ Fecha		June/Junio	2011

Municipality/Municipio	Guadalupe
2. Address / Dirección	

3. For how long have you lived in the municipality?/ ¿Por cuántos años ha vivido en el municipio?	Years/Años	

4. Sex/ Sexo	F	M

5. Age/ Edad	Years/Años	

6. Number of household memebers/ Número de personas que habitan en su casa	
7. Number of children under 14/ Número de niños menores de 14 años	

8. Education/ Educación	No Education/ Ninguna educación	Elementary/ Primaria	Secondary/ Secundaria	High school/ Preparatoria	Technical Ed./ Edu. Técnica	Higher Education/ Educación Superior	Postgraduate/ Postgrado
Complete or Incomplete/ Completa o Incompleta							

9. Water Quality/ Calidad del agua	Very bad/ Muy mal	Bad/Mal	Regular	Good/Bueno	Very good/ Muy bueno
Taste/Sabor					
Smell/Olor					
Colour/Color					

10. Your drinking water is/ Su agua de beber es…	Tap water/ De la llave	Boiled tap water/ Hervida de la llave	Bottled water/ Embotellada	Filtered tap water/ Filtrada de la llave
11. Your cooking water is/ Su agua para cocinar es…	Tap water/ De la llave	Boiled tap water/ Hervida de la llave	Bottled water/ Embotellada	Filtered tap water/ Filtrada de la llave

12. Reasons for buying bottled water/ Razones para comprar agua embotellada	Health reasons/ Razones de salud:	
	Taste/ Sabor:	
	Others/ Otros:	

13. Monthly expenditure in food/ Gasto mensual en alimentos	
14. Monthly expenditure in tap water/	

Gasto mensual en agua de la casa	
15. Number of water bottles consumed per week/ Número de garrafones consumidos por semana	
16. Bottled water price/ Precio por garrafón de agua	
17. Preferred bottled water brand/ Marca preferida de agua de garrafón	
18. Monthly household income/ Ingreso mensual del hogar	

19. Do you or a household member exhibit brown mottling of teeth? (see pictures F1 and F3) / ¿Usted o alguien en su casa presenta manchas cafés en los dientes? (ver fotos F1 y F3)	Yes/ Si	No
20. Do you or a household member exhibit patchy pigmentation of the skin? (see pictures A1 and A2) / ¿Usted o alguien en su casa presenta manchas en las palmas de las manos? (ver fotos A1 y A2)	Yes/ Si	No
21. Are there cancer patients in your family?/ ¿Algún miembro de su familia padece cancer?	Yes/ Si	No

22. In case of zero bid: could you please tell me the reason for bidding zero for the project?/ En caso de ofrecer cero: ¿podría decirme la razón por la que ofreció cero pesos por el proyecto?	

WTP Question for fluoride

Fluoride occurs commonly in Guadalupe waters. Ingestion of water containing high concentrations of fluoride can provoke dental fluorosis -an unsightly brown mottling of teeth (see picture F1)-. Higher intakes can provoke skeletal fluorosis, which can lead to fractures and crippling skeletal deformity (see picture F2). Fluorosis can manifest itself from childhood with the result that affected individuals cannot work properly and may be economically as well as physically disadvantaged for life. The Secretary of Health through the Mexican Official Norm (NOM-127-SSA1-1994) established a standard level of fluoride in drinking water. This **standard level** is exceeded if the level of fluoride is greater than **1.5 milligrams per litre**.

Monitoring results conducted by the Mexican Institute of Water Technology and the National Autonomous University of Mexico (UNAM) show that two extraction wells in your community water system (San Ramón system) have 3.05 milligrams of fluoride per litre of water extracted (that is twice the standard level). Water samples collected in September 2010 from households in Guadalupe also showed fluoride levels above the standard. Fluoride in tap water cannot be removed by boiling water or using normal household filters available in the market. Using tap water for drinking and/or cooking increases your daily intake of fluoride and the risk of develop dental fluorosis among the household members. Your community could install a new or improved treatment system that would reduce fluoride in tap water from current levels to… **PARTIAL: below the standard level established in the MON (1.5 mg/l) and some children in the community may show very mild fluorosis symptoms (see very mild in picture F3) COMPLETE: (0 mg/l) and children in the community will show no fluorosis symptoms (see Normal in picture F3)**. You could reduce your current bottled water consumption because your tap water would be safe to drink and cook. **UNRELIABLE: [However, the time you will have access to tap water will remain approximately the same.] RELIABLE: [In addition, you will have tap water 24 hours per day everyday of the year.].** But, since this would involve increased costs, it would be necessary to increase your water bill to support this treatment.

What is the **LARGEST monthly payment ABOVE** your current water bill that you would be willing to make for a new or improved treatment system and its maintenance that would reduce the level of fluoride to below the standard level in your drinking water? ______________

WTP Question for fluoride

Picture F1 Dental fluorosis

Picture F2 Skeletal fluorosis

Picture F3 Fluorosis effects

Source: Report of the Forum on Fluoridation (2002:126)

WTP Question for arsenic

Arsenic occurs commonly in Guadalupe waters. Ingestion of water containing high concentrations of arsenic may provoke skin, lung and bladder cancer and other adverse effects. Coetaneous changes due to arsenicosis include melanosis (patchy pigmentation of the skin, see picture A1), hyperkeratosis (thickening of the skin, see picture A2), desquamation and in severe cases gangrene. Anaemia and leucopoenia are highly related with chronic ***As*** exposure. The Secretary of Health through the Mexican Official Norm (NOM-127-SSA1-1994) established a standard level of arsenic in drinking water. This **standard level** is exceeded if the level of fluoride is greater than **0.025 milligrams per litre**.

Monitoring results conducted by the National Autonomous University of Mexico (UNAM) and the University of London show that two extraction wells in your community water system (San Ramón system) have 0.40 and 0.29 milligrams of arsenic per litre of water (that is 16 and 10 times the standard level respectively). Water samples collected from households in Guadalupe also showed arsenic levels above the standard. Arsenic in tap water cannot be removed by boiling water or using normal household filters available in the market. Using tap water for drinking and/or cooking increases your daily intake of arsenic and the risk of develop arsenic related diseases among the household members. Your community could install a new or improved treatment system that would reduce arsenic in tap water from current levels to below the… **COMPLETE: international standard level established by the World Health Organisation (0.01 mg/l) PARTIAL: level established by the Mexican Official Norm of 0.025 mg/l.** You could reduce your current bottled water consumption because your tap water would be safe to drink and cook. **UNRELIABLE: [However, the time you will have access to tap water will remain approximately the same.] RELIABLE: [In addition, you will have tap water 24 hours per day everyday of the year.].** But, since this would involve increased costs, it would be necessary to increase your water bill to support this treatment.

What is the **LARGEST monthly payment ABOVE** your current water bill that you would be willing to make for a new or improved treatment system that would reduce the level of fluoride to below the standard level in your drinking water?_____

WTP Question for Arsenic

Picture A1 Melanosis

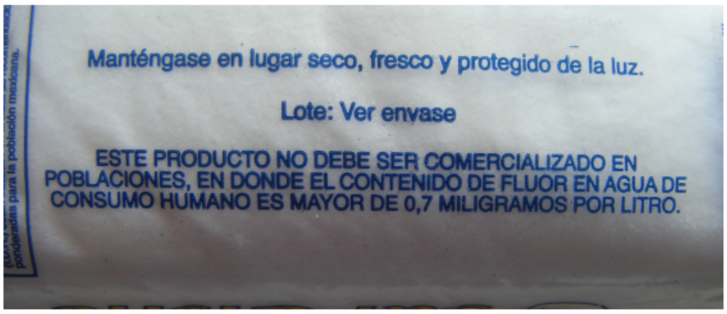
Picture A2 Hyperkeratosis

Appendix 4 Fluoridated Salt Bought in Zacatecas

Plate 1 "El Cisne" Fluoridate Salt

Iodised Fluoridated Salt
Salt Swan
Refined Salt
Net content 1 Kg

Nutritional Information
Size per portion ¼ tea spoon (1.5 g)
Approximate portions per bag 667
Quantity per Portion
Energy content 0/0 kJ (kcal)
Fat 0g
Sodium 590 mg
Carbohydrates 0g
Proteins 0g
Iodine 58%*
* The percentages of the Recommended Daily Intake are based on the recommendations table for the Mexican population.



Keep this product in a dry and fresh place away from light
Batch: See bag
THIS PRODUCT SHOULD NOT BE SOLD IN PLACES WHERE THE FLUORIDE CONTENT IN DRINKING WATER IS ABOVE 0.7 MILIGRAMS PER LITRE.

Plate 2 "La Fina Light" Fluoridate Salt

Iodised Fluoridated Salt
Salt La Fina
Refined Salt
Net content 1 Kg

Nutritional Information
Size per portion ¼ tea spoon (1.5 g)
Approximate portions per bag 667
Quantity per Portion
Energy content 0/0 kJ (kcal) **%RDI**
Fat 0g
Sodium 590 mg
Carbohydrates 0g
Proteins 0g
Iodine 60 µg 60%
Fluoride 375 mg
* The percentages of the Recommended Daily Intake are based on the recommendations table for the Mexican population.

INGREDIENTS: Sodium Chloride, Silicon Dioxide, POTASSIUM FLUORIDE from 612 to 765 MILLIGRAMS PER SALT KILOGRAM, POTASSIUM IODINE FROM 34 TO 68 MILLIGRAMS PER SALT KILOGRAM and sodium ferrocyanide.
Production Responsibility: Sales del Istmo S.A. de C.V.
Complejo Industrial Pajaritos s/n, C.P. 96400 Coatzacoalcos, Veracruz.
MADE IN MEXICO

Appendix 5 Additional Contingency Tables

Table 1. Contingency Tables for Drinking Water Sources and FDV*

FDV	DW Tap		Total	Cumulative Incidence
	0	1		
0	91	17	108	0.16
1	59	17	76	0.22
Total	150	34	184	

Risk Ratio = 1.42
Pearson chi2=1.3008 Pr = 0.254

FDV	DW Bottled		Total	Cumulative Incidence
	0	1		
0	49	59	108	0.55
1	29	47	76	0.62
Total	78	106	184	

Risk Ratio = 1.13
Pearson chi2 = 0.9502 Pr = 0.330

FDV	DW Filtered		Total	Cumulative Incidence
	0	1		
0	103	5	108	0.05
1	73	3	76	0.04
Total	176	8	184	

Risk Ratio = 0.85

FDV	DW Tap & Bottled		Total	Cumulative Incidence
	0	1		
0	96	12	108	0.11
1	71	5	76	0.07
Total	167	17	184	

Risk Ratio = 0.59
Pearson chi2 = 1.0927 Pr = 0.296

FDV	DW Tap & Filtered		Total	Cumulative Incidence
	0	1		
0	105	3	108	0.03
1	75	1	76	0.01
Total	180	4	184	

Risk Ratio = 0.47

FDV	DW Filtered & Bottled		Total	Cumulative Incidence
	0	1		
0	97	11	108	0.10
1	73	3	76	0.04
Total	170	14	184	

Risk Ratio = 0.39

*The chi-squared test was not performed when a table did not have enough data

Table 2. Contingency Tables for Drinking Water Sources and ADV*

ADV	DW Tap 0	DW Tap 1	Total	Cumulative Incidence
0	122	28	150	0.19
1	28	6	34	0.18
Total	150	34	184	
Risk Ratio = 0.95				
Pearson chi2 = 0.0191 Pr = 0.890				

ADV	DW Bottled 0	DW Bottled 1	Total	Cumulative Incidence
0	63	87	150	0.58
1	15	19	34	0.56
Total	78	106	184	
Risk Ratio = 0.96				
Pearson chi2 = 0.0509 Pr = 0.822				

ADV	DW Filtered 0	DW Filtered 1	Total	Cumulative Incidence
0	143	7	150	0.05
1	33	1	34	0.03
Total	176	8	184	
Risk Ratio = 0.63				

ADV	DW Tap & Bottled 0	DW Tap & Bottled 1	Total	Cumulative Incidence
0	136	14	150	0.09
1	31	3	34	0.09
Total	167	17	184	
Risk Ratio = 0.95				

ADV	DW Tap & Filtered 0	DW Tap & Filtered 1	Total	Cumulative Incidence
0	147	3	150	0.02
1	33	1	34	0.03
Total	180	4	184	
Risk Ratio = 1.47				

ADV	DW Filtered & Bottled 0	DW Filtered & Bottled 1	Total	Cumulative Incidence
0	140	10	150	0.07
1	30	4	34	0.12
Total	170	14	184	
Risk Ratio = 1.76				

*The chi-squared test was not performed when a table did not have enough data

Annex 1

Assessment of the Exposure to Arsenic and Fluoride from Drinking Water in the City of Guadalupe, Zacatecas, Mexico

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Abstract

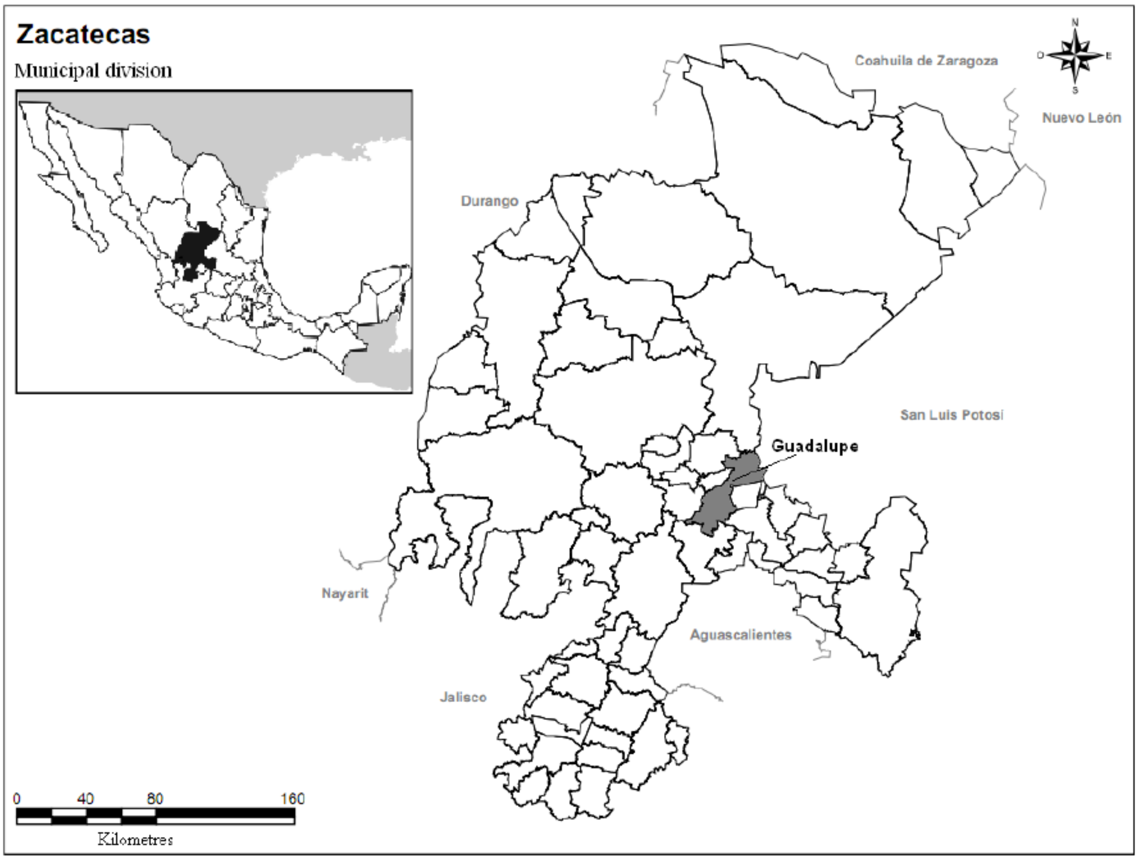
In several areas of Northern Mexico, groundwater arsenic and fluoride levels above the limits established by the Mexican guideline have been detected. An exploratory study found that in two of the extraction wells from the system that provides water to the city of Guadalupe, Zacatecas, the levels of arsenic were 10 and 16 times above the Mexican guideline. Further, the fluoride levels were two times above the guideline. There was an urgent need to characterize the risk areas for arsenic and fluoride exposure. In this study arsenic and fluoride exposures from drinking water were estimated and different risk areas in the city of Guadalupe were identified and mapped. It was found that 100% of the collected samples show levels of arsenic above the Mexican guideline of 0.025 mg/l arsenic and almost 50% of the samples have levels of fluoride above the 1.5 mg/l fluoride guideline. Women and children 0-12 years old were identified as particularly vulnerable groups. A comprehensive public policy is required to tackle this environmental problem.

Keywords: Arsenic, Fluoride, Mexico, Water Contamination

Introduction

Arsenic (***As***) and fluoride (***F***$^{-}$) have been identified among the most severe inorganic contaminants present in groundwater worldwide (Fawell and Nieuwenhuijsen 2003; Ng and Shraim 2003). In several areas of Mexico, groundwater ***As*** and ***F***$^{-}$ levels above the limits established by the Mexican Official Norm have been detected (Armienta *et al* 2010). According to the National Commission of Water, the total population living in states where there is systematic information about high levels of ***As*** and/or $\boldsymbol{F^-}$ in the waterworks is 6.4 million people (Vega 2001). The Mexican Official Norm NOM-127-SSA1-1994 (SSA 2000:77) established at 1.5 mg/L the permissible limit of $\boldsymbol{F^-}$ in drinking water and at 0.025 mg/L the permissible limit of ***As***. An exploratory study (Dávila 2013), found that the levels of ***As*** in two of the extraction wells from the San Ramón water system (which provides water to the city of Guadalupe) were 10 and 16 times above the Mexican guideline and the $\boldsymbol{F^-}$ levels were two times above the Mexican guideline. The local water authorities mix water from highly contaminated wells with water from others less contaminated as a method to reduce the levels of pollutants in the water supply of the region. This method has also been implemented in other water arsenic contaminated areas like Comarca Lagunera and Zimapán, Hidalgo (García *et al* 1994, Armienta and Segovia 2008). Therefore, it was necessary to characterize the risk areas for arsenic and fluoride exposure because there is no public information about the areas of Guadalupe fed by each group of extraction wells.

Fig. 1. Location of Guadalupe municipality in Zacatecas State



Source: INEGI. Marco Geoestadístico Municipal 2005

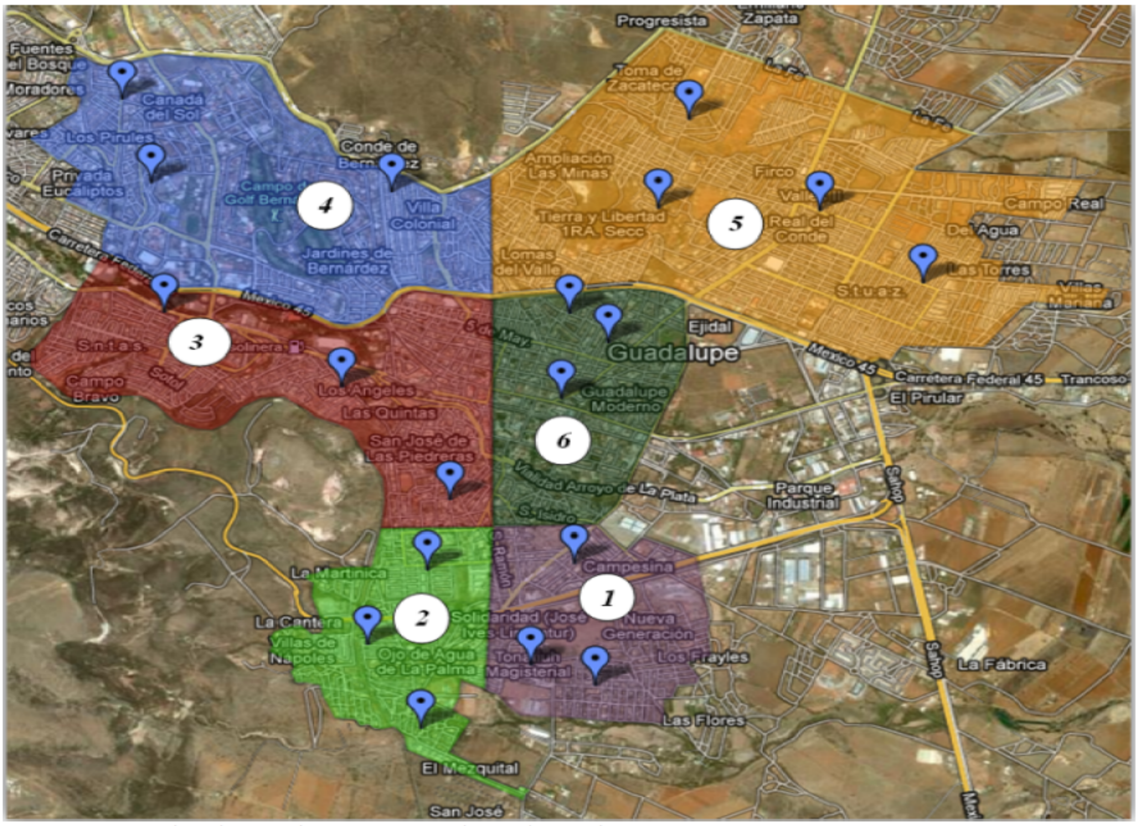
Guadalupe city is the capital of Guadalupe municipality. According to 2010 census, it has 124,623 inhabitants (INEGI 2010). Guadalupe municipality belongs to the Zacatecas State in Mexico (see figure 1). Zacatecas State is located in a semi-arid zone with an average annual precipitation of 463 mm (CONAGUA 2010:25). The average annual temperature is 17°C. The average maximum temperature is **30°C** and occurs during May. The average minimum temperature is **3°C** and occurs in January. Guadalupe municipality is located at an average 2,280 metres above sea level (lat 22° 45' N and long 102° 31' W).

1. Material and Methods

In order to characterize the risk areas for ***As*** and F^- exposure in the city of Guadalupe, the city was divided into six zones and in each zone three tap water samples[i] were obtained from randomly selected households. Each tap water sample was analysed both for ***As*** and F^-. Figure 2 presents a map of the city of Guadalupe. Each risk area is represented with numbers and the approximate locations of the homes where the water samples were collected are shown with dots. Water samples were collected in polyethylene bottles. All bottles and caps were rinsed in deionised water and washed in 10% Hydrochloric acid prior to their use. The samples were collected following the methodology in the Mexican Official Norm and tested for ***As*** and F^- at the Laboratory of Analytical Chemistry at the Geophysics Institute of the National Autonomous University of Mexico (UNAM). ***As*** contents were determined by atomic absorption spectrophotometry. F^- contents were determined using a fluoride selective electrode. Water samples were collected in July 2011 and February 2012 in order to assess ***As*** and F^- variations over time.

[i] Except in zone 6, where 4 samples were collected.

Fig. 2. Tap water sampling zones



Source: Mapped with Google Maps using the authors' data

2. Results

Table 1 shows the coordinates of the samples collection points and the main laboratory results. Table 2 shows the mean ***As*** and ***F⁻*** levels in each zone. The numbers are coloured in red if they are above the Mexican guideline. It is important to note that 100% of the samples during both collection times show levels of arsenic above the Mexican Official Norm guideline of 0.025 *mg/l* ***As.*** Further, almost 50% of the samples have levels of fluoride above the 1.5 *mg/l* ***F⁻*** guideline.

Water samples from zones 1, 3 and 6 have on average more than two times the maximum level of ***As*** allowed by the Mexican guideline. All the water samples from zones 4 and 5 are above the ***F⁻*** guideline. It should be noted that the ***As*** level in sample number 6 (zone 2) is more than 10 times above the maximum level permitted and the ***F⁻*** level is almost twice the guideline. It should be noted that the ***As*** concentrations increased in 13 out of 19 samples. On the other hand, the ***F⁻***

concentrations increased in 15 out of 19 samples. This means that in general water quality worsened over time.

Table 1 Arsenic and Fluoride levels in tap water samples collected in six different risk areas of Guadalupe, Zacatecas

Zone	Sample	Altitude	lat N	long W	pH	Conductivity
	1	2305	22° 44’ 17.8’’	102° 30’ 53.2’’	7.28	451
1	2	2296	22° 43’ 53.6’’	102° 30’ 58.5’	7.25	457
	3	2292	22° 43’ 52.5’’	102° 30’ 48.2’’	7.68	436
	4	2324	22° 43’ 43.4’’	102° 31’ 21.3’’	7.42	452
2	5	2331	22° 44’ 01.4’’	102° 31’ 26.2’’	7.57	449
	6	2331	22° 44’ 18.3’’	102° 31’ 20.6’’	7.72	604
	7	2314	22° 44’ 33.2’’	102° 31’ 15.9’’	7.87	471
3	8	2307	22° 44’ 33.2’’	102° 31’ 36.3’’	7.81	440
	9	2321	22° 45’ 19.9’’	102° 32’ 10.2’’	7.79	468
	10	2358	22° 45’ 37.2’’	102° 32’ 13.1’’	7.86	464
4	11	2392	22° 46’ 03.6’’	102° 32’ 15.5’’	7.85	455
	12	2378	22° 45’ 45.2’’	102°31’28.22’’	7.68	440
	13	2320	22° 45’ 17.7’’	102° 31’ 7.3’’	7.76	478
5	14	2322	22° 45’ 11.9’’	102° 30’ 46.8’’	7.95	470
	15	2322	22° 45’ 0.32’’	102° 30’ 52.8’’	8.02	454
	16	2318	22° 45’ 40.3’’	102° 30’ 36.0’’	7.78	451
6	17	2328	22° 46’ 0.03’’	102° 30’ 29.4’’	7.75	449
	18	2295	22° 45’ 39.2’’	102° 30’ 5.3’’	7.76	442
	19	2282	22° 45’ 24.8’’	102° 29’ 50.7’’	7.7	450

Zones were defined according to Figure 2.

Zone	Sample	Jul-11		Feb-12		Variation		% Variation	
		As	F-	As	F⁻	As	F⁻	As	F⁻
1	1	0.049	1.28	0.073	1.42	0.024	0.14	33.29	9.86
	2	0.052	1.3	0.073	1.35	0.021	0.05	28.9	3.7
	3	0.063	1.4	0.067	1.34	0.004	-0.06	6.57	-4.48
2	4	0.056	1.31	0.07	1.35	0.014	0.04	20.29	2.96
	5	0.058	1.33	0.059	1.34	0.001	0.01	2.2	0.75
	6	**0.274**	**2.85**	**0.198**	**2.33**	-0.076	-0.52	-38.18	-22.32
3	7	0.07	1.44	0.079	1.44	0.009	0	11.77	0
	8	0.072	1.59	0.029	1.82	-0.043	0.23	-148.97	12.64
	9	0.03	1.72	0.029	1.81	-0.001	0.09	-3.79	4.97
4	10	0.03	1.72	0.027	1.84	-0.003	0.12	-10.37	6.52
	11	0.029	1.75	0.028	1.81	-0.001	0.06	-4.29	3.31
	12	0.027	1.79	0.034	1.8	0.007	0.01	21.47	0.56
5	13	0.026	1.84	0.027	1.8	0.001	-0.04	2.96	-2.22
	14	0.027	1.83	0.027	1.84	0	0.01	-0.74	0.54
	15	0.03	1.82	0.051	1.66	0.021	-0.16	41.96	-9.64
6	16	0.052	1.3	0.061	1.37	0.009	0.07	14.75	5.11
	17	0.051	1.29	0.06	1.39	0.009	0.1	15.17	7.19
	18	0.06	1.3	0.067	1.37	0.007	0.07	10.15	5.11
	19	0.061	1.33	0.063	1.37	0.002	0.04	3.65	2.92

*Results for **As** and **F⁻** are in mg/L. Zones were defined according to Figure 2.*

Table 2 Mean Arsenic and Fluoride levels in tap water samples collected in six different risk areas of Guadalupe, Zacatecas in July 2011 and February 2012

Zone	n	Mean		SD		% > 0.025 mg/L As	% > 1.5 mg/L F	Range 2011-2012	
		As	F-	As	F-			As	F-
1	3	0.063	1.348	0.005	0.054	100	0	0.049 - 0.073	1.28 - 1.42
2	3	0.119	1.752	0.101	0.726	100	33	0.056 - 0.274	1.31 - 2.85
3	3	0.052	1.637	0.026	0.178	100	66	0.029 - 0.079	1.44 - 1.82
4	3	0.029	1.785	0.003	0.028	100	100	0.027 - 0.034	1.72 - 1.84
5	3	0.031	1.798	0.008	0.052	100	100	0.026 - 0.051	1.80 - 1.84
6	4	0.059	1.34	0.004	0.014	100	0	0.051 - 0.067	1.29 - 1.39

Results in mg/L are shown for each zone, as well as the arithmetical mean with the standard deviation (SD). Areas were defined according to Figure 2.

The ***As*** and ***F⁻*** levels found in sample number 6 are similar to the levels found during an exploratory study in the extraction well *San Ramón 16* that supplies water to the city (see Dávila 2013). It is possible that some areas of zone 2 are fed directly by extraction from well 16. More research is needed to confirm this hypothesis. There is a positive and strong correlation between the presence of ***As*** and ***F⁻*** in the drinking water (Pearson correlation 0.487). The correlation is significant at the 0.01 level. This relationship suggests a common source of contamination.

3. Estimation of Fluoride Exposure Doses

The following equation was used in order to calculate fluoride exposure doses in drinking water:

$$1)\ FED_{Water} = \frac{FC_{Water} \cdot \mathrm{WI}}{\mathrm{BW}}$$

Where:

FED_{Water}=Fluoride Exposure Dose in Drinking Water (*mg/kg/*day)

FC_{Water}=Fluoride Concentration in Drinking Water (*mg*/*L*)

WI=Water intake (*L*/day)

BW=Body weight (*kg*)

Chronic exposure and total bioavailability of fluoride in water was assumed. The weight and water intake of different age groups (see table 4) was obtained from the National Health and Nutrition Survey 2006 conducted by the National Institute of Public Health. Following Díaz-Barriga *et al* (1997), it was considered that infants in their first semester of life have an average body weight of 6 kg. The estimated water intake per day for infants and children was 1 L. In boiled water, fluoride level increases proportionally to the loss of volume. A risk factor for boiling the water was included, because the main source of water for infants is the one used in the reconstitution of milk formulas. Thus, the concentration of fluoride in tap water was doubled. For the minimum and maximum exposure dose calculation the mean of the water fluoride level in each zone was used.

Table 3. Weight and water intake for different age groups in Zacatecas

Age	Average weight (Kg)		Water Consumption L/Day	
	Male	Female	Male	Female
0 - 6 years	16.45	16.07	1.14	1.18
7 - 12 years	35.18	36.56	1.95	1.81
13 - 17 years	59.5	56.45	2.05	1.99
18 + years	73.02	66.17	2.26	2.1

Source: Author's calculations using information for the State of Zacatecas in the National Health and Nutrition Survey 2006.

Table 5 presents the estimation of fluoride exposure for children, teenagers and adults. Table 6 presents the estimated fluoride doses for infants. The estimated dose for the infants' group was between 0.427 mg/kg/day in zone 1 and 0.950 mg/kg/day in zone 2. For children 0-6 years old, the estimated dose was between 0.089 mg/kg/day in zone 1 and 0.209 mg/kg/day in zone 2. For children 7-12 years old, the estimated dose was between 0.071 mg/kg/day in zone 1 and 0.141mg/kg/day in zone 2. For teenagers, the estimated dose was between 0.044 mg/kg/day in zone 1 and 0.101 mg/kg/day in zone 2. And finally the estimated dose for adults was between 0.040 mg/kg/day in zone 1 and 0.090 mg/kg/day in zone 2. It should be noted that in all the zones the fluoride exposure is higher for children 0-12 years old. This is very important because dental fluorosis is provoked by high fluoride intake precisely in the stage where there is a change from temporal to permanent dentition. For example, Ortiz *et al* (1998) report that in San Luis Potosi, Mexico, in an area where the exposure dose for infants is 1.1 mg/kg/day, a prevalence of 84% was found for moderate to severe dental fluorosis. Thus, the population of children living in Zone 2 faces a clear risk of dental fluorosis.

Table 4. Estimation of Fluoride Exposure Doses in Drinking Water from Guadalupe, Zacatecas

Zone	Example	Water Fluoride intake (mg/kg/day)			
		Male		Female	
		min	max	min	max
1	Children 0-6	0.089	0.098	0.094	0.104
	Children 7-12	0.071	0.079	0.063	0.070
	Teenagers 13-17	0.044	0.049	0.045	0.050
	Adults 18 +	0.040	0.044	0.041	0.045
2	Children 0-6	0.091	0.197	0.096	0.209
	Children 7-12	0.073	0.158	0.065	0.141
	Teenagers 13-17	0.045	0.098	0.046	0.101
	Adults 18 +	0.041	0.088	0.042	0.090
3	Children 0-6	0.100	0.126	0.106	0.134
	Children 7-12	0.080	0.101	0.071	0.090
	Teenagers 13-17	0.050	0.063	0.051	0.064
	Adults 18 +	0.045	0.056	0.046	0.058
4	Children 0-6	0.119	0.127	0.126	0.135
	Children 7-12	0.096	0.102	0.085	0.091
	Teenagers 13-17	0.059	0.064	0.061	0.065
	Adults 18 +	0.053	0.057	0.055	0.058
5	Children 0-6	0.125	0.127	0.132	0.135
	Children 7-12	0.100	0.102	0.089	0.091
	Teenagers 13-17	0.062	0.064	0.064	0.065
	Adults 18 +	0.056	0.057	0.057	0.058
6	Children 0-6	0.089	0.096	0.095	0.102
	Children 7-12	0.072	0.077	0.064	0.069
	Teenagers 13-17	0.045	0.048	0.046	0.049
	Adults 18 +	0.040	0.043	0.041	0.044

For the calculation of the F^- intake, the minimum and the maximum Fluoride levels found in the 6 different risk zones of the city of Guadalupe, Zacatecas were used (see Table 1).

Table 5. Estimation of Infants' Fluoride Exposure Doses in Guadalupe, Zacatecas

Zone	Water Fluoride intake (mg/kg/day)	
	min	max
1	0.427	0.473
2	0.437	0.950
3	0.480	0.607
4	0.573	0.613
5	0.600	0.613
6	0.430	0.463

a The source of boiled water for infants is the water used in the reconstitution of milk formulas. The minimum and the maximum Fluoride levels found in the 6 different risk zones of the city of Guadalupe, Zacatecas were used (see Table 1). Following Díaz-Barriga *et al* (1997), it is considered that in boiled water, fluoride levels increase proportionally to the loss of volume. Thus, the concentration of fluoride in tap water was doubled.

The calculated doses were then compared with safety doses. The Agency for Toxic substances and Disease Registry (ATSDR 2003) has proposed a Minimal Risk Level (MRL) of 0.05 mg/kg/day for chronic oral exposure, based on the Lowest Observed Effect Level (LOAEL) of 0.25 mg/kg/day for an increased fracture rate. The maximum exposure dose to fluoride estimated for adults living in zones 1 and 6 is under the ATSDR's MRL. However, the maximum exposure dose to fluoride for adults living in zone 2 (the area with the highest fluoride levels in water) is almost two times higher than the ATSDR's MRL. It should be noted that in all cases the estimated fluoride exposure doses are higher for women. This could pose a risk in osteoporotic women of a higher fracture rate especially on those living in zones 2, 3, 4 and 5.

The total fluoride intake was calculated using the following formula:

$$FED_{Total} = FED_{Water} + FED_{Salt} + FED_{Toothpaste}$$

Following Hurtado and Gardea-Torresdey (2005), it is considered that Mexican children and teenagers consume 1.9 g/day of fluoridated salt (i.e. 250 mg $\boldsymbol{F}^{-}$/kg), and an average ingestion of 0.6 mg F–/day in toothpaste. On the other hand, Mexican adults consume, 6.9 g/day of fluoridated salt (i.e. 250 mg $\boldsymbol{F}^{-}$/kg) and 0.6 mg $\boldsymbol{F}^{-}$/day in toothpaste. It is important to note that MRL of 0.05 mg/kg/day for chronic oral exposure is surpassed in all zones once fluoridated salt consumption and toothpaste ingestion is accounted for (see Table 6). As explained in Chapter 2, fluoridated salt and toothpaste should not be allowed for selling in places where the $\boldsymbol{F}^{-}$ content in drinking water is above 0.7 mg/L (see the legend in Plate 1 "El Cisne" Fluoridated Salt in Appendix 4). Although it was found that fluoridated salt was sold during the fieldwork, the complementary survey showed that only 9% of the households reported consumption of fluoridated salt. Those households are especially at risk. The estimated doses were coloured in red in the tables if they were higher than the safety doses.

Table 6. Estimation of Total Fluoride Exposure Doses in Guadalupe, Zacatecas

Zone	Example	Water, Salt and Toothpaste Fluoride Intake (mg/kg/day)			
		Male		Female	
		min	max	min	max
1	Children 0-6	0.241	0.250	0.250	0.260
	Children 7-12	0.142	0.150	0.132	0.139
	Teenagers 13-17	0.086	0.091	0.090	0.094
	Adults 18 +	0.142	0.147	0.154	0.158
2	Children 0-6	0.243	0.349	0.252	0.365
	Children 7-12	0.144	0.229	0.133	0.209
	Teenagers 13-17	0.087	0.140	0.091	0.145
	Adults 18 +	0.143	0.191	0.155	0.204
3	Children 0-6	0.252	0.278	0.261	0.289
	Children 7-12	0.151	0.172	0.140	0.158
	Teenagers 13-17	0.092	0.105	0.095	0.109
	Adults 18 +	0.147	0.159	0.159	0.171
4	Children 0-6	0.271	0.279	0.282	0.291
	Children 7-12	0.167	0.173	0.153	0.159
	Teenagers 13-17	0.101	0.106	0.105	0.109
	Adults 18 +	0.156	0.160	0.168	0.172
5	Children 0-6	0.277	0.279	0.288	0.291
	Children 7-12	0.171	0.173	0.157	0.159
	Teenagers 13-17	0.104	0.106	0.108	0.109
	Adults 18 +	0.159	0.160	0.170	0.172
6	Children 0-6	0.241	0.248	0.250	0.258
	Children 7-12	0.143	0.148	0.132	0.137
	Teenagers 13-17	0.087	0.090	0.090	0.093
	Adults 18 +	0.143	0.146	0.154	0.157

For the calculation of the F^- intake, the minimum and the maximum Fluoride levels found in the 6 different risk zones of the city of Guadalupe, Zacatecas were used (see Table 1).

4. Estimation of Arsenic Exposure Doses

The following equation was used in order to calculate arsenic exposure doses:

1) $\mathrm{AED} = \frac{\mathrm{AC} \cdot \mathrm{WI}}{\mathrm{BW}}$

Where:

AED=Arsenic Exposure Dose (*mg/kg/*day)

AC=Arsenic Concentration (*mg/L*)

WI=Water intake (*L*/day)

BW=Body weight (*kg*)

Chronic exposure and total bioavailability of Arsenic in water was assumed. The National Health and Nutrition Survey 2006 was used for obtaining the weight and water intake of different age groups as it is shown in table 4. Infants' weight and water consumption was calculated following Díaz-Barriga *et al* (1997). The dose estimated for the infants' group was between 0.0087 mg/kg/day in zone 5 and 0.0913 mg/kg/day in zone 2 (see table 8). For children 0-6 the estimated dose was between 0.0018 mg/kg/day in zone 5 and 0.0201 mg/kg/day in zone 2. For children 7-12 the estimated dose was between 0.0014 mg/kg/day in zone 5 and 0.0152 mg/kg/day in zone 2. For teenagers the estimated dose was between 0.0009 mg/kg/day in zones 4 and 5 and 0.0097 mg/kg/day in zone 2. And finally the estimated dose for adults was between 0.0007 mg/kg/day in zone 5 and 0.0087 mg/kg/day in zone 2. The ATSDR has calculated an MRL of 0.0003 mg/kg/day for chronic ***As*** oral exposure. It should be noted that all the estimated exposure doses are above the MRL.

Table 7 Estimation of Arsenic Exposure Doses in Guadalupe, Zacatecas*

Zone	Example	Water Arsenic intake (mg/kg/day)			
		Male		Female	
		min	max	min	max
1	Children 0-6	0.0034	0.0051	0.0036	0.0054
	Children 7-12	0.0027	0.0041	0.0024	0.0036
	Teenagers 13-17	0.0017	0.0025	0.0017	0.0026
	Adults 18 +	0.0015	0.0023	0.0016	0.0023
2	Children 0-6	0.0039	0.019	0.0041	0.0201
	Children 7-12	0.0031	0.0152	0.0028	0.0136
	Teenagers 13-17	0.0019	0.0095	0.002	0.0097
	Adults 18 +	0.0017	0.0085	0.0018	0.0087
3	Children 0-6	0.002	0.0055	0.0021	0.0058
	Children 7-12	0.0016	0.0044	0.0014	0.0039
	Teenagers 13-17	0.001	0.0027	0.001	0.0028
	Adults 18 +	0.0009	0.0024	0.0009	0.0025
4	Children 0-6	0.0019	0.0024	0.002	0.0025
	Children 7-12	0.0015	0.0019	0.0013	0.0017
	Teenagers 13-17	0.0009	0.0012	0.001	0.0012
	Adults 18 +	0.0008	0.0011	0.0009	0.0011
5	Children 0-6	0.0018	0.0035	0.0019	0.0037
	Children 7-12	0.0014	0.0028	0.0013	0.0025
	Teenagers 13-17	0.0009	0.0018	0.0009	0.0018
	Adults 18 +	0.0008	0.0016	0.0007	0.0016
6	Children 0-6	0.0035	0.0046	0.0037	0.0049
	Children 7-12	0.0028	0.0037	0.0025	0.0033
	Teenagers 13-17	0.0018	0.0023	0.0018	0.0024
	Adults 18 +	0.0016	0.0021	0.0016	0.0021

*For the calculation of the ***As*** intake, the minimum and the maximum Arsenic levels found in the 6 different risk zones of the city of Guadalupe, Zacatecas were used (see Table 1). Figures in bold red are the estimated arsenic exposure doses that are 5 times above the arsenic MRL.

Table 8 Estimation of Infants' Arsenic Exposure Doses in Guadalupe, Zacatecas*

Zone	Water Arsenic intake (mg/kg/day)	
	min	max
1	0.0163	0.0243
2	0.0187	0.0913
3	0.0097	0.0263
4	0.009	0.0113
5	0.0087	0.017
6	0.017	0.0223

* The source of boiled water for infants is the water used in the reconstitution of milk formulas. The minimum and the maximum Fluoride levels found in the 6 different risk zones of the city of Guadalupe, Zacatecas were used (see Table 1). It is considered that, in boiled water, arsenic levels increase proportionally to the loss of volume. Thus, the concentration of fluoride in tap water was doubled. Figures in bold red are the estimated arsenic exposure doses that are 5 times above the arsenic MRL.

Estimated exposure doses ranging from 0.0007 mg/kg-day to 0.003 mg/kg-day provoke minor adverse health effects such as fatigue, headache, dizziness, and numbness (ATSDR 2000). It should be noted that the estimated arsenic exposure doses in all zones is above 0.0007 mg/kg-day. This means that children and adults in all the zones may experience such adverse health effects if they consume tap water. Health effects at slightly higher doses than the LOAEL of 0.005 mg/kg-day include scaling of the skin and slight changes in skin pigmentation (ATSDR 2000). The estimated maximum arsenic exposure doses for the population living in zone 2 is above the LOAEL of 0.005 mg/kg-day. More significant health effects such as significant changes in skin pigmentation (hyperkeratosis), increased blood pressure, kidney problems, and lung problems have been observed at doses in the 0.05 mg/kg/day range. None of the estimated arsenic exposure doses is above that range. However, it should be noted the in all the zones the children 0-12 years old have an estimated ***As*** oral exposure dose at least five times higher than the MRL. Therefore, this age group can be identified as particularly affected. Besides, the maximum exposure dose to arsenic for the adults in Guadalupe living in zone 2 (the area with the highest arsenic levels in water) is almost 30 times higher than the ATSDR's MRL. The estimated doses were coloured in red in the tables if they were higher than the safety doses.

5. Discussion and Conclusions

This research identified and characterized six different risk areas for arsenic and fluoride exposure in the city of Guadalupe, Zacatecas, Mexico. Arsenic and fluoride dose exposures from drinking water were estimated and the different risk areas in the city of Guadalupe were mapped. It was found that 100% of the samples collected show levels of arsenic above the Mexican guideline of 0.025 *mg/l* arsenic and almost 50% of the samples have levels of fluoride above the 1.5 *mg/l* fluoride guideline. In all the zones the calculated fluoride and arsenic exposure doses for children 0-12 years old are higher than the Minimal Risk Levels established by the Agency for Toxic Substances and Disease Registry. The 0-12 age group can be identified as particularly affected. This is very important because a high incidence of dental fluorosis has been reported in the area (see Aguilera et al 2009). It is important to remember that high fluoride intake during the change from temporal to permanent dentition provokes dental fluorosis. It should be noted that the estimated fluoride exposure doses are in all cases higher for women. Consumption of water with high levels of fluoride could pose a risk of higher fracture rates among osteoporotic women especially on those living in zones 2, 3, 4 and 5. Therefore, women can also be identified as a group potentially affected by the high levels of fluoride in water. Households consuming fluoridated salt are at higher risk in all areas. Therefore, it is very important to raise awareness of the risks associated with the consumption of fluoridated salt among local health, water and commerce officials and the general population. Further research is required to assess other potential health risks. A comprehensive public policy is required to tackle this environmental problem.

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Annex 2

Plants and soil contamination with heavy metals in agricultural areas of Guadalupe, Zacatecas, Mexico

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Introduction

The environmental impact of mine tailings has been largely documented around the world. Deterioration and contamination of soils, groundwater and superficial water as well as alterations in the hydrological systems have been associated with mining wastes (Figueroa *et al* 2010). Heavy metal contamination of plants, soil and water affects several countries worldwide posing a serious threat to the health of millions of people. Due to its long mining history, Mexico is among the most affected countries by this serious environmental problem.

A geochemical comparative study was conducted in the municipality of Guadalupe in Zacatecas, Mexico. The objectives were to measure the bioconcentration factor in maize (*Zea mays L.*) plants in function of their heavy metal absorption, to identify the toxicity order of heavy metals in sampled plants to assess potential environmental impacts taking into account the particularities of the selected crop and to evaluate the potential consequences on the region's food security.

Zacatecas state is located in north central Mexico (see figure 1). There, metallic ores are abundant and diverse. The state has 450 years of mining tradition with the consequent accumulation of mining tailings (Salas–Luévano *et al* 2009). Currently,

[j] Osiel González Dávila contributed in the literature review, in the geographical delimitation and in the collection of plant and soil samples. He helped in the preparation of plant and soil samples in the laboratory. He co-authored the results, discussion and conclusions sections. He wrote sections 3.3 and 3.4 and typed and proofread the text.

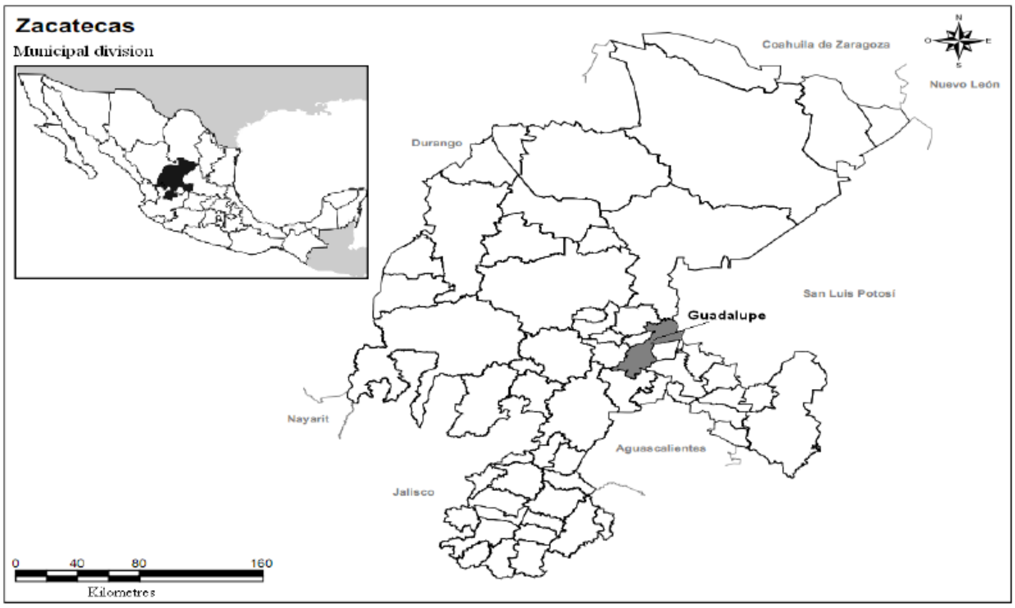
[k] Juan Miguel Gómez-Bernal contributed in the literature review, in the geographical delimitation and in the collection of plant and soil samples. He prepared and analysed plant and soil samples in the laboratory. He co-authored the results, discussion and conclusions sections.

[l] Esther Aurora Ruíz-Huerta contributed in the literature review, in the geographical delimitation and in the collection of plant and soil samples. She prepared and analysed plant and soil samples in the laboratory. She co-authored the results, discussion and conclusions sections.

Zacatecas state is the most important silver producer in Mexico. During the year 2010, 1,855,145 kilograms of silver were produced in Zacatecas (INEGI 2011). Amalgamation for silver extraction, also known as patio process, consists in adding mercury to the silver ore in order to obtain a silver amalgam as the final product. Amalgamation was used extensively throughout the period from 1570 to 1820. Most of the heavy metals lost via amalgamation were carried by rivers and deposited in the plain areas of the Zacatecan valley in what is now the Guadalupe municipality. Most of these areas are currently used for crop farming since there are no restrictions imposed by the Mexican authorities (Santos–Santos *et al* 2006).

Previous studies have found high levels of Pb, As, Hg and F^{-} in groundwater extraction wells that supply Guadalupe municipality (Leal and Gelover 2002; Castro *et al* 2004; Dávila 2011). In addition to drinking water health risks, there is also risk of potential levels of heavy metals entering the food chain via absorption by crops from contaminated soil and water. Heavy metal contaminated crops could aggravate human health risk when consumed along with heavy metal contaminated drinking water (Brammer 2008; Duxbury 2007; Santos–Santos *et al* 2006). The most important staple food in Mexico is maize. Meals are based on maize, with tortillas providing much of the caloric intake both in rural and urban areas. Due to its importance for the food security of the region, it was decided to analyse the contents of heavy metals in maize plants.

Figure 1 Location of Guadalupe municipality in Zacatecas State



Source: INEGI. Marco Geoestadístico Municipal 2005

1. Methods and materials

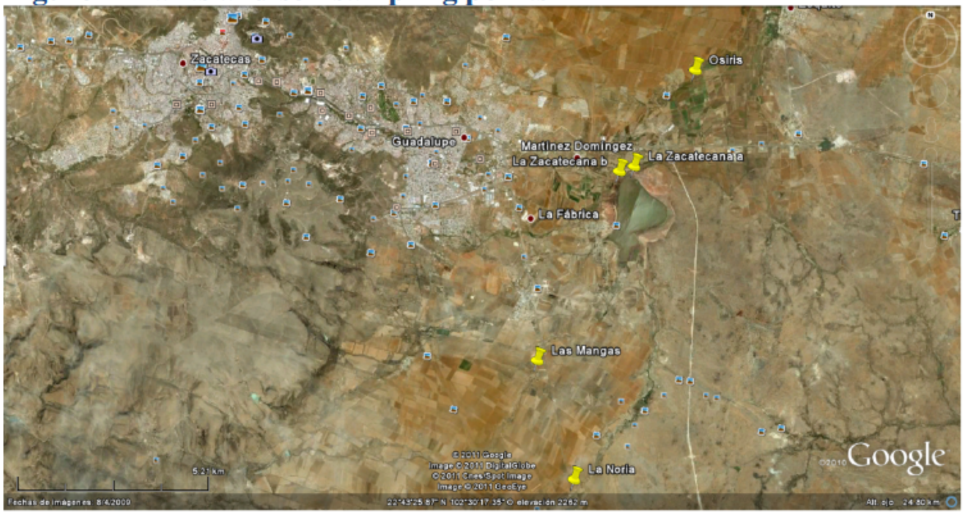
1.1 Geographical delimitation

Soil and maize plant samples were collected from agricultural areas from the municipality of Guadalupe, Zacatecas. Guadalupe municipality is located at an average 2,280 metres above sea level (lat 22° 45' N and long 102° 31' O). The site is characterized by a climate arid sub tropic tempered throughout the year. The average annual temperature is 17°C. The average maximum temperature is 30°C and occurs during May. The average minimum temperature is 3°C and occurs in January. There is an average annual precipitation of 463 mm (CONAGUA 2010:25). Due to Zacatecas' climate and environmental conditions, irrigation is very important in maize production. According to the Service of Agrifood and Fishery Information (SIAP 2010), in Zacatecas 34,918 hectares of land producing maize were irrigated during 2010. Soil and plant samples were collected from 5 different irrigation zones in the municipality during June 2011. In the southern part of the municipality, samples were collected from agricultural land in Noria Blanca and Las Mangas. In the central part, samples were collected from La Zacatecana and in the northern part samples were collected from agricultural land in Osiris. The coordinates of sampling points can be found in table 1. The map in figure 2 shows each of the collection points.

Table 1 Sampling points coordinates

	Zone	Alt	lat N	long W
1	La Noria	2267	22° 40′ 02.1′′	102° 28′ 52.5′′
2	Las Mangas	2254	22° 41′ 46.5′′	102° 29′ 28.1′′
3	La Zacatecana a	2220	22° 44′ 37.2′′	102° 27′ 55.5′′
4	La Zacatecana b	2223	22° 44′ 32.1′′	102° 28′ 09.6′′
5	Osiris	2190	22° 46′ 02.2′′	102° 26′ 56.8′′

Figure 2 Plants and soil sampling points



Source: Mapped with Google Earth using the authors' data

1.2 Sample Size

The number of samples n was calculated with the formula: $n = [Za^2 * p * (1-p)] / d^2$. A 95% confidence level was established and a *Za* of 1.96 was obtained. Following Santos-Santos *et al* (2006), a proportion value p of 0.05 and a precision factor d of 8.5% were selected. Thus, the number of samples n was calculated as 25.26 samples. Thus, it was decided to collect five maize plant and soil samples in a 100 m^2 area of agricultural land in each irrigation zone. Nevertheless, 2 extra samples were collected because mine tailings were found next to agricultural land in zone 3.

1.3 Soil samples analysis

Soil pH was measured in soil-H2O suspension (1:2.5, w/w) and electrical conductivity was measured in a 1:5 soil to water suspension using an HI 9828 Multiparameter portable (HANNA instruments) with intelligent probe and T.I.S. Total N was determined using the Kjeldhal method (Black 1965). Organic matter content was determined by the Walkley and Black procedure (Nelson and Sommers 1982). Available P was measured colorimetrically by the molybdenum blue method (Olsen and Sommers 1982). Soil samples were dried at 60 °C for 75 h; then each sample was crushed, sieved (< 325 μm), homogenized, and weighed. Soil particle size distribution was measured using the hydrometer method (Allen *et al* 1974). Carbonate content was determined following Horton and Newson (1953) methodology. Available (DTPA-extractable) heavy metal concentrations (Pb, Cd, Fe, Cu and Mn) were determined by atomic absorption spectrophotometry. Total heavy metals in soil and plant samples were measured by energy-dispersive X-ray fluorescence spectrometry, using a NITON XL3t of Thermo Fisher Scientific. X-ray spectra were analyzed with Niton Data Transfer software suite. The spectrometer was calibrated for heavy metals using certified standards from NIST (National Institute of Standards and Technology) Montana soil 2711 and 2710a and peach in plants. Intermediate and high heavy metal concentration standards, traceable to NIST, were prepared in our facility to have a wide range calibration curve. Heavy metals concentrations in the samples were measured three times. Arsenic (a metalloid) in soils and plants samples was also determined using energy-dispersive X-ray fluorescence. This technique has been accepted by the U.S. Environmental Protection Agency to measure arsenic in dry solid samples (Melamed 2004:4).

1.4 Plant samples analysis

Plant samples were collected from the top layer (0-30 cm) of agricultural land. They contained a mix of spoil and soil. Thus, samples were washed thoroughly in the laboratory with running tap water, followed by three rinses with deionized water (18 MΩcm-1, Milli-Q Millipore) and a rinse of tri-distilled water. All plant samples were carefully divided into shoots and roots. They were dried at 60°C for 75h. The oven-dried plant samples were then crushed, sieved (< 325 μm), homogenized, and weighed. Later, arsenic and heavy metal concentrations were determined by energy dispersive X-ray fluorescence. The translocation factor (TF) for metals within a given plant was calculated as metal concentration in shoot divided by that in root (Tu *et al* 2003; Rizzi *et al* 2004). The bioconcentration factor (BFC) was expressed by the ratio of metal concentration in plant above ground part to total metal concentration in soil (Rotkiittikhun *et al* 2006).

2. Results

2.1 Soil samples results

Table 2 shows the results of total concentrations for the following elements: Pb, As, Hg, Zn, Cu, Fe, Mn and K. All the results are expressed in ppm. Tests for Cd, Ag and

Ni were also conducted but the concentration levels were in all samples under the limit of detection. In zones 1 to 4, at least five soil samples were collected. In zone 5, three soil samples were collected. Sample 17 corresponds to a tailing sample collected in zone 3 from a tailing pond located next to agricultural land (see figure 3).

Table 2 Arsenic and heavy metal concentrations (ppm) in agricultural soils of Guadalupe, Zacatecas.

Zone	Sample	Pb	As	Hg	Zn	Cu	Fe	Mn	K
1 La Noria	zac-1	28.69	< BDL	< BDL	72.78	< BDL	21828.6	481.24	11771.6
	zac-2	26.02	< BDL	< BDL	74.26	< BDL	23137.2	506.34	11193
	zac-3	29.13	< BDL	< BDL	76.33	< BDL	23575.2	581.25	12148.7
	zac-4	26.17	< BDL	< BDL	87.78	< BDL	21849.3	494.12	8126.95
	zac-5	23.34	< BDL	< BDL	69.91	< BDL	23030	519.22	10738.2
	zac-6	22.6	< BDL	< BDL	73.64	< BDL	21620.9	495.55	8555.12
2 Las Mangas	zac-7	52.04	15.92	< BDL	109.4	< BDL	19778.2	527.64	14058.3
	zac-8	28.44	12.91	< BDL	64.54	< BDL	18523.3	622.17	12772.8
	zac-9	20.93	< BDL	< BDL	72.4	< BDL	19323.8	365.46	12529.6
	zac-10	27.25	13.14	< BDL	70.06	< BDL	19240.8	560.97	14183.9
	zac-11	36.43	14.06	< BDL	98.65	< BDL	22773.7	525.42	11743.6
3 La Zacatecana A	zac-12	534.94	87.4	16.69	997.27	95.41	36453.5	928.08	13191.9
	zac-13	660.34	163.34	20.73	1392.47	113.17	37976.4	927.29	11631.4
	zac-14	644.52	143.82	18.58	1233.23	114.26	38234.1	895.54	12067.5
	zac-15	518.84	85.53	< BDL	882.36	105.6	35873	812.61	13470.3
	zac-16	552.36	94.51	< BDL	946.45	95.36	35726.3	914.2	11438.5
	zac-17*	**5660.25**	**289.9**	**505.9**	**10086.5**	**1323.82**	**55330.6**	**1792.39**	**10466.4**
4 La Zacatecana B	zac-18	540.39	70.64	< BDL	889.6	113.49	34742.6	783.97	12821.7
	zac-19	572.71	68.82	21.92	955.41	107.81	35413.9	859.98	11564
	zac-20	661.17	90.95	17.9	1110.74	146.63	36420.7	945.89	14131.8
	zac-21	634.74	59.41	25.27	1049.17	136.21	36023.1	818.63	12606.4
	zac-22	625.63	77.22	25.51	1042.01	145.5	39214	824.22	12492.4
	zac-23	639.82	68.28	20.5	982.33	132.9	35100	749.13	11480.9
	zac-24	540.39	70.64	37.69	1303.11	147.76	35619.1	1189.53	12795.9
5 Osiris	zac-25	105.58	< BDL	< BDL	182.35	56.2	40001.9	780.22	9100.29
	zac-26	88.65	21.39	< BDL	161.41	55.2	40888.1	707.06	9434.11
	zac-27	105.96	< BDL	< BDL	188.72	64.5	44801.5	816.88	9836.79

Results for Pb, As, Hg, Zn, Cu, Fe, Mn and K are in ppm. Areas were defined according to fig 2

* Sample 17 corresponds to a mine tailing sample collected in zone 3.

< BDL = Below detection limit.

Table 3 shows the pH and electrical conductivity in the soil samples. The samples collected in zones 1, 2 and 5 are moderately alkaline. Soil samples from zones 3 and 4 are slightly alkaline. The organic matter was also determined. It should be noted that the percentage of organic matter in soils samples collected in zones 3 and 4 is higher than in the rest. This can be explained by the fact that wastewater irrigation is a common practice in that specific area. The other parameters shown in the table are total nitrogen, phosphorous and calcium carbonate. The high levels of phosphorus and total nitrogen found in samples from zones 3 and 4 are congruent with the levels of organic matter found. Table 4 shows the available (DTPA-extractable) heavy metal concentrations in ppm. It should be noted that the availability of such elements is higher in zones 3 and 4. This is congruent with the information shown in table 2.

Table 3 Chemical analysis of agricultural soils of Guadalupe, Zacatecas.

Zone	pH	EC dS/m	OM %	TN %	P (ppm)	$CaCO_3T$ %
1 La Noria	8.288	1.206	1.294	0.062	20.55	1.814
2 Las Mangas	7.872	0.538	1.628	0.127	16.08	0.602
3 La Zacatecana A	7.686	3.57	3.868	0.192	59.1	3.058
4 La Zacatecana B	7.602	2.704	4.062	0.208	74.71	3.152
5 Osiris	8.304	1.678	1.494	0.072	8.48	1.458

Areas were defined according to fig. 2. EC=Electrical Conductivity, OM= Organic Matter, TN = Total Nitrogen.

Table 4 Available (DTPA-extractable) heavy metals in agricultural soils of Guadalupe, Zacatecas.

Zone	Pb	Cd	Fe	Cu	Mn
1 La Noria	0.562	0.013	3.56	0.588	17.38
2 Las Mangas	2.314	0.086	8.664	1.344	29.844
3 La Zacatecana A	67.94	5.036	74.228	35.808	23.44
4 La Zacatecana B	85.656	4.284	33.306	29.688	26.81
5 Osiris	4.138	0.574	3.528	5.546	15.214

Results for Pb, Cd, Fe, Cu and Mn are in ppm. Areas were defined according to fig. 2

Figure 3 Tailing pond close to agricultural land in Guadalupe, Zacatecas.

2.2 Plant samples results

The concentrations of Pb, As, Zn, Cu, Fe and Mn in the roots and shoots of maize plants collected in the study area are summarized in table 5. In zones 1 to 4, at least five maize plant samples were collected. In zone 5, three maize plant samples were collected. Tests for Cd, Hg, Ag and Ni were also conducted. However, the levels of those elements were under the limit of detection in all samples.

Table 5 Arsenic and heavy metal concentrations (ppm) in roots and shoots of maize plants collected in Guadalupe, Zacatecas.

Zone	Samples	Pb	As	Zn	Cu	Fe	Mn
1	Roots	NA	15.26	153.97	74.45	11174.63	295.83
	Shoots	NA	NA	94.38	69.87	766.66	324.03
2	Roots	NA	NA	31.13	42.75	1053.51	NA
	Shoots	NA	NA	89.02	81.58	956.74	271.69
3	Roots	293.24	98.15	849.74	111.49	25359.64	629.71
	Shoots	21.39	NA	688.63	121.71	2196.75	150.1
4	Roots	79.77	44.14	462.5	213.63	11357.48	223.24
	Shoots	16.8	NA	438.07	120.35	1565.75	263.69
5	Roots	18.55	NA	236.69	89.84	13233.08	318.83
	Shoots	NA	NA	177.69	104.57	1992.08	485.14

2.3 Bioconcentration and translocation factors in plant samples

Table 6 shows the bioconcentration and translocation factors for metals in maize plant samples. The toxicity order is discussed in section 3.2.

Table 6 Bioconcentration and translocation factors

Zone	Factor	Pb	As	Zn	Cu	Fe	Mn
1	BCF	NA	NA	2.02	NA	0.49	0.57
	TF	NA	NA	0.61	0.94	0.07	1.1
2	BCF	NA	NA	0.38	NA	0.05	NA
	TF	NA	NA	2.86	1.91	0.91	NA
3	BCF	0.5	0.85	0.78	1.06	0.69	0.7
	TF	0.07	NA	0.81	1.09	0.09	0.24
4	BCF	0.13	0.6	0.44	1.64	0.32	0.24
	TF	0.21	NA	0.95	0.56	0.14	1.18
5	BCF	0.19	NA	1.33	1.53	0.32	0.42
	TF	NA	NA	0.75	1.16	0.15	1.52

3. Discussion

3.1 Soil contamination

The Mexican Official Norm NOM-147-SEMARNAT/SSA1-2004 (SEMARNAT 2007) established the following guideline values for arsenic and heavy metals in agricultural soil in 2007:

Table 7 Mexican guideline values for arsenic and heavy metals in agricultural soil

Element	Guideline value (ppm)
As	22
Cd	37
Hg	23
Ag	390
Ni	1600
Pb	400

This study has identified arsenic, lead and mercury contamination in agricultural soil from Guadalupe, Zacatecas (see table 2). Table 8 presents the mean, standard deviation (SD) and range of Pb, As and Hg concentrations found in the five sampling zones. Zones 3 and 4 located in La Zacatecana are the most contaminated. All the soil samples collected in those areas are above the 400 ppm maximum allowed level of Pb in soils established by the Mexican Official Norm. Although Pb concentrations are lower than those reported in other mining regions in Mexico (see for example Gutiérrez-Ruiz *et al* 2007 that report a Pb range of 972-16,881 ppm), the Pb contamination levels are unquestionably high and toxic. Arsenic concentrations were also high in the studied areas -ranging from 15.92 to 163.34 ppm- even compared to those reported in other mining regions from Mexico (see for example Mendoza-Amézquita *et al*. 2006 that report As concentrations of 21-36 ppm) and North America (Moldovan *et al*. 2003 report As concentrations of 56-6,000 ppm). It should be noted that all the samples in zones 3 and 4 are above the 22 ppm As guideline. However, As concentrations found in this study were low compared to concentrations reported by Méndez and Armienta (2003) in Zimapan, Hidalgo, Mexico (2,550-14,600 ppm) and Ortega-Larrocea *et al* (2009) for the same area (up to 2,869 ppm). On the other hand, three soil samples from zone 4 were above the 23 ppm Hg guideline. Hg contamination is not evident in zones 1,2 and 5. Table 9 shows that there is a strong positive correlation between the presence of Pb and As in soils of the region. The correlation is significant at the 0.01 level. This relationship suggests a common source of contamination and it is very likely that it is related to the same kind of mining activities. It is very important to mention that during the fieldwork the authors found that a local mining company dug a tailing pond and was filling it with mining waste just 13 meters away from agricultural land in zone 3 “La Zacatecana a” (see figure 3). High heavy metal levels were found in the tailing sample collected there.

In their exploratory study, Santos–Santos *et al* (2006) reported that the main source of heavy metal contamination in Guadalupe’s soil is related to old mining activities carried out in the surrounding area of Osiris and La Zacatecana. However, it was found that new mine tailings in the area are recklessly managed and there is an alarming lack of enforcement mechanisms to oblige the mining companies to obey the environmental laws and regulations. Those new tailings are undoubtedly a source of heavy metal contamination of the neighbouring agricultural land. Although Manzanares *et al* (2003) reported normal levels of lead and mercury in blood of sampled people at La Zacatecana, it is very likely that those concentrations have increased over time. Two heavy metal exposition routes can be identified. In the first place, there is a respiratory intake of particles and dust from contaminated soil. Second, as it is explained in the following section, there is a deposition of heavy metals in crops aimed for human consumption. Therefore, a blood study should be conducted again among the people of the region. Due to the presence of the new mine tailings in the region, a higher exposure to heavy metals is expected

Table 8 Mean Lead, Arsenic and Mercury levels in soil samples collected in five different risk areas of Guadalupe, Zacatecas

Zone	*n*	Pb				As				Hg*			
		Mean	SD	Range	% > 400 ppm Pb	Mean	SD	Range	% > 22 ppm As	Mean	SD	Range	% > 23 ppm As
1	6	25.99	2.67	22.60 - 29.13	0	<BDL	NA	< BDL	0	< BDL	NA	< BDL	0
2	5	33.02	11.98	20.93 - 52.04	0	14.01	1.37	12.91 - 15.92	0	< BDL	NA	< BDL	0
3	5	582.20	65.44	518.84 - 660.34	100	114.92	36.12	85.53 - 163.34	100	18.67	2.02	16.69-18.58	0
4	7	602.12	50.02	540.39 - 661.17	100	72.28	9.76	59.41 - 90.95	100	24.80	6.95	17.9-37.69	43
5	3	100.06	9.89	88.65 - 105.96	0	21.39	NA	21.39	0	< BDL	NA	< BDL	0

Results for Pb, As and Hg are in ppm. Areas were defined according to Figure 2. < BDL = Below detection limit. * For the mean and SD calculation for Hg samples under the limit of detection were excluded.

Table 9 Correlation levels of Lead and Arsenic

		Pb	As
Pb	Pearson Correlation	1	.865**
	Sig. (2-tailed)		.000
	N	27	18
As	Pearson Correlation	.865**	1
	Sig. (2-tailed)	.000	
	N	18	18

**. Correlation is significant at the 0.01 level

3.2 Plants contamination

Soils from zones 3 and 4 have the highest levels of heavy metal concentrations (see tables 2 and 4). High levels of heavy metals were also found in plants collected in those areas. Plants from zones 1 and 2 showed lower heavy metal concentrations than plants from the other 3 zones. Toxic levels of Cu and Zn in plants were found in all zones except zone 2. One of the objectives of this study was to measure the bioconcentration and the transference factor in maize plants and to indicate the toxicity order of heavy metals in the plants. It was found that the amount of metals was higher in roots and shoots of plants growing in the most contaminated soil of zones 3 and 4. Consistent with other works (Bidar *et al*., 2007; Marques *et al*., 2009), heavy metal accumulation occurred more frequently in roots than in shoots. The BCF shows that there is a higher accumulation of Zn and Cu in maize plants. In some zones, Zn concentration exceeded by two of times the critical limits proposed by Kabata-Pendias (2001) (see table 10). The BCF factor in zone 1 was 2.02 for Zn, followed by 0.57 for Mn and 0.49 for Fe. The other metals were not detected. In zone 2 the BCF was 0.38 for Zn and 0.05 for Fe. In zone 3, the BCF was Cu>As>Zn>Mn>Fe>Pb. The BCF in zone 4 was Cu>As>Zn>Fe>Mn>Pb. And in zone 5, the BCF was Cu>Zn>Mn>Fe>Pb>As. The order of the sampled sites in relation to their BCF from lower to higher is: zone 2 < zone 1 < zone 5 < zone 4 < zone 3. In regards to the translocation factor (TF), in zone 1 it was Mn>Cu>Zn>Fe>Pb>As. In zone 2 it was Zn>Cu>Fe>Mn>Pb>As. In zone 3 it was Cu>Zn>Mn>Fe>Pb>As. The TF in zone 4 was Mn>Zn>Cu>Pb>Fe>As and in zone 5 it was Mn>Cu>Zn>Fe>Pb>As. The TF shows a higher concentration of Cu, Zn and Mn in the shoots of maize plants and a lower concentration of Pb and As.

Table 10 Ranges of heavy metals reported to be toxic for plants

Element	Ranges of toxic concentrations in plants (ppm)
Pb	30-300
As	5-20
Hg	1-3
Zn	100-400
Cu	20-100
Mn	400-1000

Source: Kabata-Pendias (2001)

3.3 Implications for food security and human health

There is consensus in the literature that the food chain (soil–plant–human in this case) is one of the most important routes for human exposure to metalloids and heavy metals (see for example USDA 2000, Järup 2003, Wang et al 2005, Khan et al 2008 and Zhuang 2009). High heavy metal concentration in soils is toxic to humans and other animals and exposure through the food chain is usually chronic (i.e. the exposure takes place over longer periods of time) (USDA 2000). According to the FAO (2003), food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. The very fact that new mine tailings have been found right next to agricultural land in the study area should be considered a threat to food safety and human health. The results show that maize plants accumulate As and heavy metals. Maize is the most important staple food in Mexico and the samples analysed were aimed for human consumption. It should be highlighted that in zones 3 and 4 the accumulation of Pb and As in maize plants is very high. Those elements are highly toxic and they are bioaccumulated and transferred to the food chain. This is of particular relevance because of the potential adverse effects on health and food security of people in the region.

Exposure to Pb provokes a number of diseases, including mild mental retardation as well as anaemia, gastrointestinal effects, increased blood pressure, and hearing loss. It also has effects on the reproductive system, as well as genotoxicity, carcinogenicity and social effects (WHO 2004). According to Järup (2003), children may absorb up to 50% of the Pb contained in food and adults around 15%. Pb is accumulated in the skeleton and its release is slow. It remains in the blood around one month and in the skeleton between 20 and 30 years. In adults, inorganic Pb does not penetrate the blood–brain barrier. In contrast, children are more susceptible to Pb exposure and subsequent brain damage because of their high gastrointestinal uptake and the permeable blood–brain barrier. Acute Pb poisoning presents an array of different symptoms that include headache, irritability, abdominal pain and other symptoms related to the nervous system. Sleeplessness and restlessness are characteristic symptoms of encephalopathy related to Pb exposure. In particular, children may be affected by behavioural changes, learning and concentration difficulties. Acute psychosis, confusion and reduced consciousness are reported in severe cases of Pb encephalopathy. The World Health Organisation (2009), estimated that Pb exposure was responsible for 0.6% of the global burden of disease (expressed in disability-adjusted life years, or DALYs) and 143,000 deaths in 2004. These figures take into account mild mental retardation and cardiovascular outcomes resulting from exposure to lead.

According to the WHO (2001), the principal contributor to the daily intake of total As is usually food. The daily intake of total As from food and beverages ranges between 20 and 300 µg/day. However, in the specific case of Guadalupe, arsenic in drinking water is a significant source of As exposure (see Annex 1). There, As in drinking water constitutes the principal contributor to the daily As intake. As discussed in Chapters 1 and 2, chronic exposure to As in drinking water is linked to excess risk of mortality from lung, bladder and kidney cancer. The risk increases with higher As exposure. There is also an increased risk of skin cancer and other skin lesions, such as hyperkeratosis, melanosis and gangrene. Contaminated soils such as mine tailings can be identified as an important source of As exposure, mainly in zones 3 and 4. Two exposition routes are identified: the respiratory intake of particles and dust as well as plants absorption. Studies on various populations exposed to arsenic by inhalation (e.g. miners and smelter workers) in different countries constantly demonstrate an excess lung cancer (Järup 2003). Pulmonary exposure may contribute up to approximately 10 µg/day in a smoker and more in contaminated areas. Lokuge et al (2004) estimated that As-related diseases result in 9,136 deaths per year and 174,174 DALYs lost per year in populations exposed to water As concentrations higher than 50 µg/L.

A second reason of concern is the high levels of Mn, Zn and Cu found both in soils and plants. It should be noted that Cu and Zn are not considered toxic for humans but are toxic for plants and for this reason some countries have posed restrictions to their concentrations in soil. This is of particular relevance because a higher concentration of these elements could hinder the development of plants and could reduce land productivity and access to food. Påhlsson (1989), states that in general plant growth is affected at 1000 µg Zn/L (1 ppm) or more in a nutrient solution. However, she also notes that 100 to 200 µg Zn/L (0.1 to 0.2 ppm) may provoke cytological disorders. Concentrations of 100 to 200 μg Cu/L (0.1 to 0.2 ppm) disturb the plant's metabolic processes and growth. In the specific case of maize plants, Huerta et al (2012) compared the development of maize plants in two different locations after 70 days. Plants obtained in agricultural soils far from tailings grew on average 46 cm. In contrast plants obtained in tailings grew 24 cm on average. Their results show that heavy metals and metalloids in zones close to tailings affect the development of young maize plants, disturb their growth and cause phytotoxic effects that are shown in their appearance.

3.4 Policy Options

Given the high concentrations of As and heavy metals found both in soils and plants samples a number of policy options should be considered in the region. The correct disposal of mining waste is one of the key aspects of any policy proposal to tackle the problems related to plants and soil contamination. The risk of exposure to toxic elements through the food chain can be reduced enforcing the environmental laws and regulations already in place. For example, the General Law for Prevention and Integral Waste Management (SEMARNAT 2003) established the legal and institutional framework for developing and enforcing waste management programs at municipal level. This law also established the right to information and created the National Information System for Integral Waste Management that should contain information about the local situation, waste stock, the infrastructure available for its management, bylaws and other laws relevant for waste regulation and control. In addition, the Mexican Official Norm NOM-147-SEMARNAT/SSA1-2004 (SEMARNAT 2007) has already established guideline values for arsenic and heavy metals in agricultural soil. On the other hand, in July 2013 the Federal Law of Environmental Responsibility entered into force (SEMARNAT 2013). This law is important because at its core includes the "polluter pays principle." It aims to force the polluter to restore the environment to its pre-pollution status. It also establishes fines, penalties, compensations and criminal liability if environmental damages are caused intentionally and/or recklessly. The EU Environmental Impact Assessment Directive (85/337/EEC) in force since 1985 provided a precedent for the Mexican Law.

On the other hand, policies aimed to reduce or contain the levels of toxic elements in the environment should be considered. According to the USDA (2000) it is very difficult to eliminate metals from the environment. Once metals contaminate the environment, they will remain because metals do not degrade like organic molecules. The only exceptions are mercury and selenium, which can be transformed by microorganisms. Traditional treatments for metal contamination in soils include high temperature treatments that produce non-leachable material, the use of solidifying agents that produce cement-like material that can be removed and washing processes that leaches out contaminants. However, those processes are expensive. According to the USDA (2000:6), traditional cleanup in situ may cost up to \$100.00/m^3 whereas removal of contaminated material (ex situ) may cost up to \$300/m^3. Phytoremediation is an alternative mitigation option that is effective in environments contaminated with As and heavy metals. Phytoremediation is a general term for using plants to remove, degrade, or contain soil contaminants. In contrast to traditional treatments, phytoremediation may only cost \$0.05/m^3.

Phytoremediation depends on the capability of certain plants to capture high amounts of metals that are then transferred to the aerial parts where they are accumulated. Phytoremediation includes five technologies: phytostabilization, phytoextraction, phytovolatilization, phytodegradation and rhizofiltration. However, only phytostabilization has been efficient for soils contaminated with metals (Juárez-Santillán et al 2010). Phytostabilization requires the establishment of a plant cover on polluted areas. A reduction on the mobility of contaminants is achived through the accumulation of toxic elements by roots or within the rhizosphere. This process reduces leaching, controls erosion and adds organic matter to the substrate that binds the contaminants. Plant species that tolerate high levels of contaminants and tailings are used in phytostabilization (Bolan et al 2012). Santos–Santos et al (2006) suggest introducing native plants in contaminated areas of Zacatecas where dust is generated since respiratory and ingestion processes are the most important source of exposure. For example, *C. lindleyi* has been identified among the native Mexican plants that can be adapted to environments with mining waste and that can accumulate heavy metals. Due to its features it is a strong candidate for its use in phytoremediation in Zacatecas (Gómez-Bernal et al 2014). Some other plant species have been identified as good candidates for phytoremediation of mining areas of central Mexico. It has been documented that *Opuntia lasiacantha* retains arsenic and heavy metals in the root and *Nicotina glauca* accumulate arsenic, cadmium, lead, copper and zinc in its aerial parts (Santos-Jallath et al 2012). These plants can be used for reforestation of mining waste areas in Guadalupe.

On the other hand, the evidence presented in this paper shows that maize plants accumulate heavy metals and As. Therefore, the production of maize or any other crops aimed for human consumption in the conatminated zones should be restricted. However, it is acknowledged that the restriction or complete prohibition of agricultural production in the region can provoke protests and social unrest given the economic and cultural importance of agriculture and in particular of maize production. Thus, an integrated environmental policy should take into consideration the scientific research conducted in the region in order to update and accurately assess the different environmental problems. At the same time, it is necessary the participation of the different stakeholders in the region (members of the local community, farmers and mining companies, environmental and health officers, etc.) in the design of appropriate policies.

Conclusions

The aim of this research was to provide an assessment of heavy metal contamination in five agricultural zones of the Guadalupe municipality in Zacatecas, Mexico. High levels of arsenic, lead and mercury contamination in agricultural soil were found in two irrigation zones. High levels of Zn and Cu were found both in soils and plants in all the areas. Heavy metal absorption in maize plants aimed for human consumption was calculated using the bioconcentration and the translocation factors. The accumulation of Pb and As in plants was very high. Those metals are highly toxic and could be bioaccumulated and transferred to the food chain. Further, high levels of Zn and Cu were found both in soils and plants. Although they are not considered toxic for humans, they are toxic for plants. Several studies have found that high concentrations of these elements hinder the development of plants and could reduce land productivity. A strong and positive correlation of concentration of arsenic and lead in soil suggests that there is a common source of such contaminants. In several areas of Zacatecas state mining activities (some of them using cyanidation) and tailing reprocessing activities are currently being developed. It was found that new mine tailings in the area are recklessly managed (see figure 3). Those new tailings are undoubtedly a source of heavy metal contamination of the neighbouring agricultural land. This should be considered as a threat to health and food safety of the people in the region. Maize plants accumulate heavy metals and As. Thus, the production of maize for human consumption in the highly contaminated zones should be restricted to reduce the exposure to toxic elements through the food chain. Respiratory and ingestion routes are the most important sources of heavy metal exposure. Considering the high concentration levels found for arsenic, lead and mercury in soils of two irrigation zones of Guadalupe, mitigation activities should be implemented. Phytoremediation is a viable mitigation option. A number of studies indicate that native Mexican plants, such as *C. lindleyi, Opuntia lasiacantha* and *Nicotina glauca* could be successfully used to remove heavy metals and metalloids from soils contaminated with mining waste. Future environmental policies should promote the participation of all relevant stakeholders and make an intensive use of science. There is an urgent need to conduct more research on potentially contaminated agricultural areas. Further health and environmental risk assessments should be promptly conducted in the region.

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